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"The "D" Open Pit - Reclamation"

by

David Rezansoff
Environment Supervisor - Cluff Lake Mine

and

Brian Tarry
Environment Coordinator - Cluff Lake Mine

and

Curtis J. Andrews
Technical Manager

Cogema Resources Inc.
817 - 825 45th Street West
Saskatoon, Saskatchewan, Canada
S7K 3X5

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The “D” Open Pit - Reclamation

Dave Rezansoff, Brian Tarry, Curtis J. Andrews

Abstract

COGEMA Resources Inc. operates the uranium mines and mill at Cluff Lake in Northern Saskatchewan. Several uranium deposits have been mined or are currently being mined by either open pit or underground methods at the Cluff Lake site. One of these deposits, the “D” deposit, was discovered in 1970 and mined as an open pit in 1979 and 1980. The deposit yielded 150 000 tonnes of ore at an average grade of 3.0% uranium.

The company’s philosophy is to reclaim and decommission areas on the mining lease as soon as possible after mining work has been completed. With regulatory agency approval, the “D” Open Pit area could be the first to be decommissioned at Cluff Lake.

Since the mining of the ”D” pit was completed, the surface facilities have been removed and the area has been recontoured, covered with a layer of local overburden and revegetated. Vegetation was reestablished by hydroseeding the area with a seed mix that was developed on site and which was suited to local soil conditions. The overburden at the “D” site is virtually barren of nutrients when compared to farmlands in the southern part of the province and required the addition of fertilizer at a rate of 850 kg/ha. In addition mulch is also required along with tackifier when seeding on steeper slopes. A thick thatch developed within a few years after completion of the revegetation program. This thatch initially inhibited the invasion of native plants but now shrubs and trees are starting to invade the area.

The water collecting in the former open pit, the groundwater and surface waters have been monitored extensively since 1985 as part of the mine site license requirements. Results to date indicate that the upper 10 metres of water in the pit will meet Saskatchewan Surface Water Quality Objectives (SSWQO). If the water were to overflow the pit area into Boulder Creek it is expected that these objectives would still be met. Also the pit water has had no detectable effect on the surrounding ground water chemistry.

The D pit area is an excellent example of the sustainability of mining in Northern Saskatchewan from initial discovery of a deposit, through mining, finally to decommissioning and returning the area to nature with minimal overall impact.

1. *Introduction*

Cogema Resources Inc., operates the uranium mines and mill at Cluff Lake in Northern Saskatchewan (Figure 1 & 2). Operations began in 1979 with mining of the D deposit located about 1 Km east of the northern end of Cluff Lake in the Boulder Creek valley. Following the mining of D, other deposits including Claude, OP, Dominique Peter and Dominique-Janine were or currently are being mined.

At the completion of the operation at D, the company in consultation with the Atomic Energy Control Board (AECB) and Saskatchewan Environment and Resource Management (SERM) began efforts to reclaim the area affected by mining. These efforts included removal of buildings, settling ponds, other infrastructures and low grade ore stockpiles, recontouring the surface, revegetating the area, and monitoring surface water and groundwater.

The D pit and surrounding area has been extensively monitored and documented over the past twelve years. The results of the monitoring indicate that conditions are stabilizing at levels that meet regulatory limits. This would allow the company to make application to the regulatory bodies to officially decommission the area and therefore demonstrate that land used for mining might be returned to the public domain.

2. *History*

2.1. *General History*

The D ore body was discovered in 1969 by AMOK LTD. (now Cogema Resources Inc.) following an airborne scintillometer survey and geological mapping of mineralized boulder trains (Figure 3). The D ore body was situated in a geologically complex area near the perimeter of the central metamorphic rock core of the Carswell Structure (Amok 1992). The D deposit was located at the overturned contact between the overlying Athabasca Formation and the underlying metamorphosed basement rock (Figure 4 & 5).

The D ore body was located entirely within the Boulder Creek Basin. Groundwater flow within the Boulder Creek basin is gravitational flow infiltrating downwards beneath the upland areas. Groundwater also flows upward and longitudinally beneath the valley of Boulder Creek. It is considered that groundwater discharges upward into the Boulder Creek alluvium and that the entire regional groundwater discharges to Boulder Creek. The surface water from Boulder Creek moves downward into Boulder Creek alluvium west of D ore body to Cluff Lake. During the operation of the D ore body the entire Boulder Creek was intercepted and diverted past the open pit in a semi-circular steel flume. This flume and associated dam upstream of the D orebody were removed in 1993.

In 1979 and 1980, D was mined as an open pit. The pit reached the dimensions of 203m x 90m x 28m deep. The deposit yielded 150 000 tonnes of ore at an average grade of 3.0% uranium.

During the operation of the pit, minewater was collected and treated locally before being released to the environment. After mining was complete in 1981 the water treatment plant operated between April and October. For the rest of the year water was hauled to the mill and used as process make-up water. In July 1981 run-off from a major rainstorm could not be effectively contained and additional berms were constructed.

In April 1983, the pit was flooded by Boulder Creek. The creek returned to its normal channel a few days after the flood occurred. A dyke was constructed between Boulder Creek and the pit in August.

During 1983, all surface facilities were removed and the surface was contoured so that most run-off would flow to the pit. All grades were reduced to 25 degrees or less. The waste rock stockpile was also contoured and 20 centimeters of overburden was placed on top to provide a rooting medium for vegetation.

In 1985, the final earthworks in the immediate area of D, grading the waste rock stockpile, was completed.

In 1993, approval was received to remove the half culvert which lined Boulder Creek and to breach the dam upstream of D. Final contouring of the breach in the dam was completed in 1994 and the area of the breach was hydroseeded.

2.2 Monitoring History

The D-pit area was first monitored by a regional piezometer network, as well as a surface water monitoring program, beginning in 1977-1979. Boulder Creek was sampled at upstream and downstream locations, before, during and after mining. In 1983, after D-pit filled with water, in-pit water quality measurements commenced, and monitoring of selected piezometers continued. This monitoring continues to date.

2.3. *Revegetation History*

In 1981 field studies began on finding the optimum species for the revegetation of the D mining area. Samples of soil and rock from the D area were used in the studies, resulting in the following seed mixture:

	1983		**1984**
25%	hair grass	26%	slender wheatgrass
15%	red fescue "fortress"	20%	red fescue "fortress"
5%	red fescue "arctared"	7%	red fescue "arctared"
5%	Kentucky bluegrass "sydsport"	14%	fowl bluegrass
5%	Kentucky bluegrass "troy"	7%	Kentucky bluegrass "sydsport"
20%	slender wheatgrass	7%	Kentucky bluegrass "troy"
10%	fowl bluegrass	7%	lax alkali grass
5%	weeping alkali grass	6%	annual bluegrass
5%	annual bluegrass	6%	reed canary grass
5%	reed canary grass		

Additional seed	white spruce	150 g/ha
	Jackpine	150 g/ha

This seed mixture was used in the first major revegetation program conducted in 1983. Reseeding of some areas was done in 1984. Grass cover in the fall of 1984 was dominated (80%) by hairgrass and Kentucky bluegrass that was split evenly at 40%. Red fescue that showed very well in a test was not found. The final seeding of the waste rock stockpile area was completed in 1985. Presently the most dominate of the original species is reed canary grass, which showed poorly in 1984. The vegetation is now well established in the D-pit area, and native species are starting to invade the area (see Section 4.3).

2.4. *Studies*

To date, there have been two specific studies done in the D-pit area. First, from 1986 to 1988, a detailed study of the D-pit area was initiated by Saskatchewan Environment and Cogema Resources Inc. (S.E.R.M., 1993). There were three purposes of this study; "I) determine the physical and chemical changes taking place in the water column; ii) identify the external influences, if any, affecting these changes, and; iii) determine how these changes relate to arsenic concentrations and Saskatchewan Surface Water Quality Objectives" (S.E.R.M., 1993).

This initial study produced several important conclusions, including 1) water quality of D-pit is affected by pit water turn-over and run-off; 2) run-off events, during the spring melt and summer showers, concentrate major ions, metals and radionuclides towards the bottom of the pit; 3) area groundwater has not shown signs of significant contaminant migration.

The second study began in 1992, focusing on the water quality of the D-pit water column, and continues to date. Since 1993, Cogema Resources Inc. assumed full responsibility for this program.

2.4.1. Local Piezometer and Boulder Creek Analyses

Figures 6 to 8 show the raw historical data collected from key monitor wells, located on the south side of D pit and along Boulder Creek.

The raw data for Boulder Creek, upstream and downstream of D-pit is also shown (Figures 9 and 10).

Groundwater quality in the vicinity of D-pit showed limited effects as a result of mining. Immediately south of the pit, (Figure 6) slight increases in sulfate and uranium concentrations occurred after mining, while conductivity and chloride remain at or near pre-mining levels. Groundwater radium concentration has decreased as a result of mining. Nickel concentration is slightly elevated, and arsenic has shown no change.

Downstream of D-pit similar effects were seen in the groundwater quality, with minor elevation of sulfate and uranium concentrations (Figures 7 and 8). Slight increases in sulfate and uranium concentrations occurred, while radium concentrations have decreased substantially after D-pit mining was completed.

Mining in this area appears to have improved local groundwater quality, from pre-mining conditions, with respect to radium concentration.

Water quality results for Boulder Creek upstream of D-pit for arsenic, nickel, Ra-226 and U indicate that this creek was un-affected by mining in this area (Figure 9). During the mining phase, increases in these parameters occurred (Figure 10), specifically between 1980 and 1982.

The last 10 years of monitoring has shown downstream of the pit consistently low concentrations of these parameters, all well within the Saskatchewan Surface Water Quality Objectives (S.S.W.Q.O.). Based on these results, Boulder Creek water is expected to continue to be of excellent quality in the future.

3. Current Monitoring

3.1 What is Monitored Now

Table 1 shows the current status of monitoring in the D-pit. As in previous years, the sample type has remained with the same type of analysis, but the frequency was increased from once per quarter to monthly. This increase in sampling frequency was made to accommodate the second D-pit study, which focused on pit water quality. Additional monthly measurements of temperature, conductivity, and dissolved oxygen were also taken at one metre intervals. To clarify interpretation, field data is examined at five metre intervals in this report.

Weather has been monitored near the Cluff Lake mill since 1981, with an Environment Canada Meteorological Observation station. Data collected (Figure 11) can be indirectly applied to the D-pit area.

3.2. What Trends area Being Observed

3.2.1 Weather

The weather information shown (Figure 11) depicts the normal, average mean values for each month since 1981. The highest average temperature occurs in July, with an average value of 16.8°C. The lowest average temperature occurs in January, with an average value of -19.6°C. Maximum average monthly precipitation is found in July, at 82 mm precipitation, while the lowest value is 17.1 mm in February. The bulk of the spring melt typically occurs in April and May. During the 1986 - 1988 study of D-pit, it was estimated that approximately 7 000 m^3 of spring runoff water enters D-pit, primarily from accumulated snow in the highlands immediately north-east of the D minesite area.

3.2.2 Field Measurements

Table 2 shows the field measurements taken during the current study period, up to August 1995. Figure 12 shows the monthly averages of this data.

Pit water temperature shows seasonal fluctuation at surface and the 5 metre depth. Below 5 metres, the pit shows a definite thermal stratification with an average temperature of 3.6°C, and only the top 5 metres of water being affected by seasonal temperature fluctuation.

Surface conductivity is affected primarily by the spring melt between April and May of each year, giving a 20% decrease in surface water conductivity. At 5 metre and 10 metre depths, conductivity decreases throughout the summer months, with corresponding increases at 15 metres during the summer. At 20 metres, conductivity remains relatively constant throughout the year, at about 1.4 times greater than measurements at 15 metres and above. The lowest point in conductivity at a depth of 20 metres is found in May, in conjunction with the distribution of melt water throughout the pit water. There is thus a definite conductivity stratification in the pit water throughout the year, occurring between 15 metres and 20 metres. This indicates the presence of a stable chemocline at this depth.

Dissolved oxygen results show that recharge occurs between September and November, to a depth of 15 metres. This event is related to the decreased temperature of surface water and at 5 metres during the fall, and to a slight decease in conductivity at the 15 metre depth in September. Dissolved oxygen at the 0 to 5 metre depths consistently meets or exceeds the SSWQO minimum for dissolved oxygen of 6.0 mg/L throughout the year. At a depth of 20 metres, dissolved oxygen concentration is typically very low or absent, and a hydrogen sulfide odour is consistently present.

3.2.3 Analytes

Figures 13 through 17 show the concentrations of arsenic, nickel, Ra-226 and U in D-Pit water, at surface, 5 m, 10 m, 15 m and 20 m, For ease of interpretation, the following summary is based on the individual selected parameters, for the current study period beginning April 1992. Refer to the Figures listed above for each individual element.

Arsenic (Figure 14)
Surface water arsenic concentrations continue to be well below the SSWQO of 50 μg/L. Arsenic levels tend to 'bottom out' in the spring, corresponding to dilution by spring melt, and have not exceeded 20 μg/L since January 1993.

At 5 metres, arsenic concentration declined for the past 3 years, and was consistently lower than 40 μg/L. The arsenic concentrations at surface and 5 m have shown strong similarity since April 1992. A similar trend is seen for arsenic at the 10 metre level. At 15 metres, definite spikes in arsenic concentration are seen, usually between August and October. This was evident in the fall of 1992 and 1993, and was less prominent in 1994. This indicates that, during thermal stratification effect in the fall, some arsenic-bearing sediment mixes with the water at the 15 metre depth, then quickly settles down. There is no indication that this is affecting the water quality from surface to 10 metres.

At 20 metres, arsenic concentrations have increased from an average of about 700 µg/L in April 1992 to an average of about 1100 µg/L, where this concentration has remained for the past 2 years.

Nickel (Figure 15)
In 1994, the average concentration for nickel at surface was 0.019 g/L, with a high of 0.029 mg/L, and a low of 0.007 mg/L. There has been a downward trend in nickel concentration at surface, since April 1992. Similar results are seen at the 5 metre and 10 metre depths. At 15 metres, nickel concentration has fluctuated around the 0.030 mg/L concentration, with a high of 0.042 mg/L and a low of 0.016 mg/L. At 20 metres, nickel has shown a definite downward trend.

Nickel concentration appears to show stratification, with highest concentrations found at the 15 metre depth.

Ra-226 (Figure 16)
Between surface and 10 metres, Ra-226 concentrations have generally been below the SSWQO of 0.11 Bq/L, with the lowest values between June and August, when dilution effects due to rainfall/runoff are greatest. Ra-226 concentrations at 5 metre and 10 metre depths have been less than or equal to 0.05 Bq/L since April 1992.

At the 15 metre depth, the maximum concentration of radium has been 0.16 Bq/L, in September 1994. Peak concentrations at this level tend to occur between April and September. The 20 m depth has shown a general rise in Ra-226 concentration since April 1992, with a plateau of 0.25 Bq/L since August of 1993.

Uranium (Figure 17)
Uranium concentrations from surface to 10 metres have shown very similar downward trends since April 1992. The SSWQO of 200 µg/L U has been met since April 1993. The 15 metre U concentration appears to show stabilization and decreasing concentrations since December 1993, below the 200 µg/L level. From April 1992 to October 1993, uranium concentration rose at the

20 metre depth. The concentration now appears to be stabilized, between 200 μg/L and 225 μg/L.

4. Future Predictions

4.1. Resuspension of Bottom Sediments

Previous studies on D-pit (S.E.R.M., 1993) discussed the possibility of bottom sediments acting as a sink for metals and radionuclides. With the exception of nickel, there tends to be a concentration gradient for contaminants in D-pit, with the lowest levels found near the surface, and the highest levels found at 20 m. The greatest degree of variation in concentrations is found at the 15 metre level (Figure 14), with peak concentrations of arsenic, nickel, radium-226 and uranium occurring in July through September. In contrast, concentrations at the 20 m level remain relatively stable throughout the year. This suggests that, during the late summer or fall, some resuspension of materials from 20 m or deeper does occur, but only up to the 15 metre depth. Resuspended materials then precipitate back to the 20 m depth or below.

Thermal turnover appears to be the primary factor affecting these seasonal changes in chemical concentrations at the 15 metre depth. The chemocline, however, remains intact throughout the year

Resuspension events can also depend on wind/wave action, and presence/absence of ice cover. However, the D-pit is in a small, sheltered basin, so wind effects are thought to be minimal, and at this latitude ice cover is virtually guaranteed.

4.2 When Will The Pit Overflow to Boulder Creek?

D-pit water elevation is shown in Figure 18, for the past 10 years. Yearly averages are shown, along with the high and low values for each year. From 1985 through 1991, pit water elevation rose approximately 12 cm per year, to an average elevation of about 332.25. Higher average water levels from 1992 to July 1995 resulted in a much slower rate of rise, of approximately 1.35 cm per year.

This slower rate of rise is due to two main factors. First, the water elevation has passed the confines of the pit, into a much larger collection area as defined by the south road/berm structure. Second, with the increased water elevation, seepage of pit water into the Boulder Creek alluvium has probably increased.

As the hydraulic head of the pit increases, so will the amount of seepage of pit surface water into the Boulder Creek alluvium. The rate of rise will probably decrease accordingly, and reach a point of equilibrium.

Three possible long-term scenarios are suggested for the D-pit area and are indicated below. In all cases, D-pit surface water quality is expected to meet the S.S.W.Q.O.

Long -Term Scenarios for D-pit Area

Water Elevation		Boulder Creek	
		does not overflow into D-Pit	Overflows into D-Pit (ice jams in Boulder Creek, beaver dams etc.)
D-Pit	does not overflow (stays below 334.20 m.a.s.l.	1. Pit water level will determine amount of water seepage into Boulder Creek alluvium	
	does overflow (exceeds 334.20 m.a.s.l.)	2. Sediment build-up in pit seals seepage areas, eventually increasing the pit water elevation over the road.	3. Amount of water entering the pit exceeds the amount of seepage from the pit.

This first scenario is that neither the pit nor the Boulder Creek overflow. This is the current status of the D-pit area. If this situation were to continue, water quality data suggests that the SSWQO will continue to be met in the pit, to a depth of at least 10 metres.

The second scenario would occur if Boulder Creek does not overflow, and the level of the pit slowly rises to fill the basin defined by the south road/berm structure. The pit would then overflow into Boulder Creek at the lowest point on the top of the road/berm structure, at 334.2 m.a.s.l.. This could occur as the sediment layers accumulate in the pit, eventually sealing off seepage areas. This scenario should not adversely affect the water quality of the top 10 metres of pit water, since this would occur slowly, over several years or decades. Any water which would be decanted from the pit to Boulder Creek at that time would be expected to meet the S.S.W.Q.O..

The third scenario would occur if Boulder Creek was to overflow into D-pit, causing the pit to fill to the lowest point on the road/berm structure (334.2 m.a.s.l.), and flow back into Boulder Creek. This had occurred in April 1983, prior to the construction of the road/berm structure. The potential exists for an ice jam, beaver dam, or similar restriction in Boulder Creek to cause this to occur again in the future. This mass input of water into the pit would probably cause some stirring of pit water at depth, and temporally elevate the concentrations of some parameters in the pit surface water. It would be expected that, following an event of this nature, the pit water level would reach an equilibrium, and settling would return the pit water quality to its present state within a short period of time, meeting the S.S.W.Q.O.

4.3 Vegetation - Natural Vegetation Encroachment

During the past 12 years, succession has been observed throughout the D-pit minesite. Species observed now include alder, moss, lichen, mixed grasses, jack pine, aspen, cattails and bulrushes.

5. Conclusion

The reclamation of the D-pit area represents the first attempt at officially reclaiming an open pit uranium mine. It is an excellent example of the sustainability of mining in Northern Saskatchewan. Extensive monitoring and documentation over the past twelve years indicates that reclamation activities appear to have been successful, with the S.S.W.Q.O. generally being met to a depth of 10m in the pit. Pit water does not appear to have affected downstream groundwater quality, and natural vegetation is becoming well-established in the area. The results of the monitoring indicate that conditions are stabilizing at levels that are expected to continue to meet regulatory limits. Ultimately, the present state of the D-pit mine will be considered to be the accepted decommissioning condition for this area, and will allow the Company to make application for the release of this property as an officially decommissioned mine site.

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Table 1 Current Monitoring Status of D-pit Water Quality

1994 Operating License **Sample Location**	**Parameters**	**Frequency**
D-Pit Water	water elevation	Monthly, during ice-free months
	Class C* water analyses at 5m intervals	Monthly

1994 Extended Monitoring Program **Sample Location**	**Parameters**	**Frequency**
D-Pit Water	conductivity, pH, temperature, dissolved oxygen at 1m intervals	Monthly
	Class C* random duplicate analysis	Monthly

* Class C water analysis - Total analysis for - CO3/HCO3**, Ca, Cl, Mg, K, Na, SO4, TSS, Ra-226, U, As, Cu, Fe, Ni, Zn, Pb, pH, conductivity, total hardness, sum of ions, turbidity

** CO3/HCO3 - When pH is greater than 8.3, report CO3 and HCO3. When pH is less than 8.3, report HCO3 only.

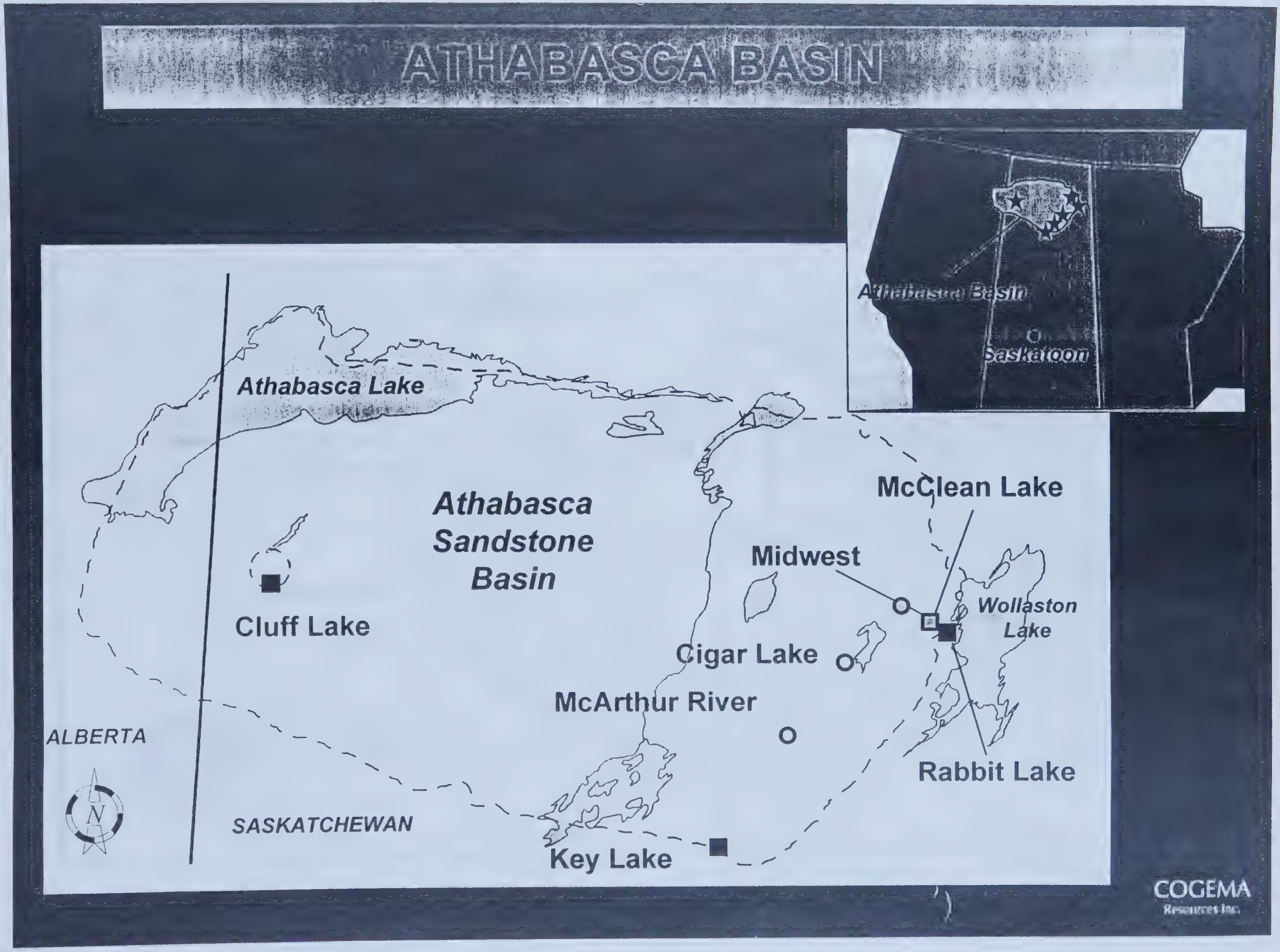
D-PIT FIELD MEASUREMENTS
Average By Month - Apr.1992 to Aug. 1995

FIELD DATA FOR “D” PIT SURVEY

Table 2

1992-1995

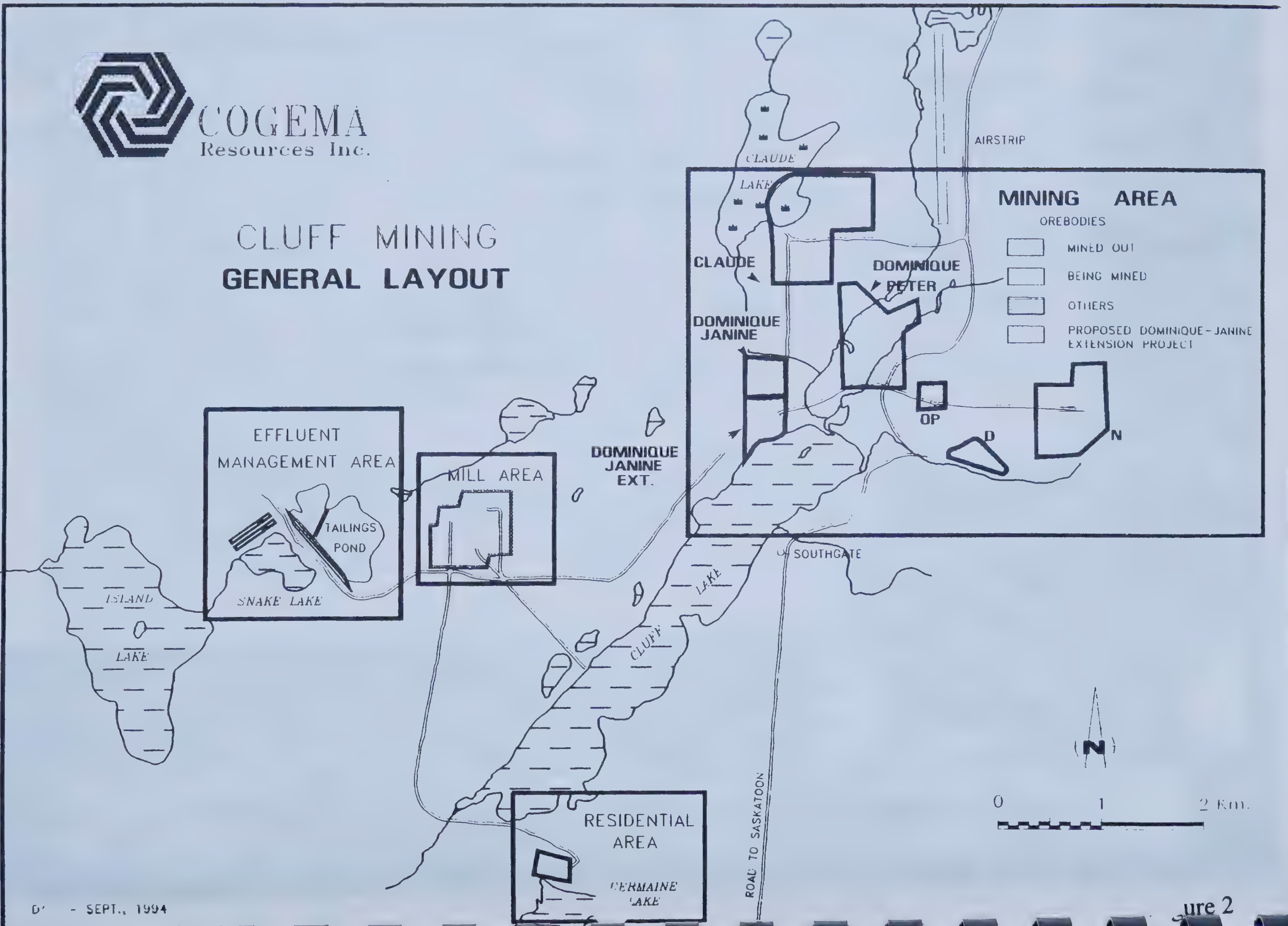
	Temperature (°C)					Conductivity (mS/cm)					Dissolved Oxygen (mg/L)				
	0 m	5 m	10 m	15 m	20 m	0 m	5 m	10 m	15 m	20 m	0 m	5 m	10 m	15 m	20 m
Apr-92	0	3.2	3.3	3.2	3.4	29	176	180	186	315	10.8	4.7	3.6	1.6	0.1
May-92	6	5.3	4.3	3.2	3.2	161	162	165	188	248	10.5	9.45	7.2	1	0.53
Jun-92	17	5.9	4.1	3.1	3.1	159	161	175	197	267	9	7.5	4.2	0.5	0.7
Jul-92	21.1	6.2	4.2	3.8	3.4	161	162	178	202	268	9.2	7.79	2.6	0.29	0.39
Aug-92	18	7.5	4.2	3.7	3.2	156	159	176	206	255	7.2	5.25	2.2	0.5	0.55
Sep-92	7.5	5.6	5.2	3.6	3.5	161	162	167	215	268	7.72	7.8	6.4	0.75	0.52
Oct-92	1.5	2.5	4.1	4.4	4.7	185	186	188	199	297	7.6	7.1	6.55	5.27	0.25
Nov-92	0.9	3.2	3.3	3.5	3.7	176	171	175	183	271	12.4	9.6	8.7	6.7	0.5
Dec-92	0.1	3.4	3.5	3.5	3.7	181	180	184	193	275					
Jan-93	0.2	3.4	3.5	3.5	3.7	202	272	194	209	299					
Feb-93	0.4	3.3	3.5	3.5	3.7						11.8	6.7	5.1	3.1	0.5
Mar-93	1.5	3	3.1	3.1	3.6	75	175	180	180	265	8.6	5.6	4.2	3.2	1.2
Apr-93	12.8	5	3.2	3	3.2	175	190	195	210	320	11.3	5.6	4.2	2.4	1.7
May-93	16.8	5.8	3.5	3.4	3.5	174	180	195	220	320	11.3	5.6	4.2	2.4	1.7
Jun-93	19.2	8.4	3.8	3.7	3.7	167	178	200	229	330	9.3	6.2	2.7	0.9	0.3
Jul-93	17.9	9.2	3.9	4.1	3.8	164	179	199	226	314					
Aug-93	11.3	10.9	3.9	4.1	3.8	169	169	202	224	327					
Sep-93	5.2	4.8	4.8	4.1	3.8	211	210	209	258	364					
Oct-93	0.3	3.1	3.3	3.4	3.8	205	189	189	194	329					
Nov-93	0.4	3.2	3.3	3.4	3.8	207	190	190	194	331					
Dec-93	0.2	3.3	3.4	3.4	3.8	207	190	190	194	331					
Jan-94	0.2	3.3	3.4	3.4	3.8	194	189	193	198	335					
Feb-94	0.4	3.2	3.4	3.5	3.8	207	211	212	222	371					
Mar-94	0.4	3.2	3.4	3.4	3.8	199	210	214	224	349	6.6	6.3	4.6	4.1	0.6
Apr-94	0.3	3.3	3.4	3.4	3.8	194	211	216	223	368	7.6	6.5	4.8	4	0
May-94	9.1	5.1	4.6	3.8	3.7	177	178	178	190	306	12	9.1	8.3	5.5	0.1
Jun-94	20.9	6.9	4.6	4	3.8	250	208	180	196	340	10.5	8.9	7	3.1	0.2
Jul-94	14.5	7.3	4.6	4	3.8	176	173	182	195	348	9.9	7.3	5.7	1.3	0.1
Aug-94	19.7	8.3	4.5	4	3.8	178	172	182	208	352	9.2	5.7	4.3	0	0
Sep-94	13.4	11.2	4.6	4.1	3.8	175	174	183	214	355	9.4	8.1	3.3	0.1	0.1
Oct-94	8.4	7.5	4.9	4.2	3.8	174	175	181	207	348	10.5	11.6	4.3	1.5	0.1
Nov-94	1.1	3.6	3.7	3.8	3.8	208	207	206	209	389	11.6	10.8	9.8	9	0.6
Dec-94	0.1	3.4	3.7	3.6	3.7	202	205	207	210	389	9.4	8.9	7.9	7.2	0.2
Jan-95	0.1	3.5	3.6	3.6	3.6	204	185	189	191	350	8.4	7.3	6.2	5.8	0.1
Feb-95	0.1	3.4	3.6	3.6	3.6	197	203	208	211	380	8.2	7.7	6.7	6.2	0.2
Mar-95	0.9	3.5	3.6	3.6	3.6	202	202	208	212	385	5.8	7.5	6	5.1	0.1
Apr-95	0.2	3.5	3.6	3.6	3.6						6.7	7	5.8	4.8	0.2
May-95	13.9	3.7	3.5	3.6	3.6	149	189	193	201	358	6.7	3.4	2.6	1.6	0
Jun-95	17	4.2	3.6	3.6	3.6	149	180	187	194	344	8.6	3.4	2.4	1.4	0.2
Jul-95	16.9	5.5	3.6	3.6	3.6	214	205	207	221	393	11.7	4.9	3.8	0.2	0.1
Aug-95	16.1	7.4	3.7	3.6	3.6	210	207	206	219	390	11.4	8.2	6	0.2	0.1



ATHABASCA BASIN

Athabasca Basin
Saskatoon
Athabasca Lake
Athabasca
Sandstone
Basin
Cluff Lake
McClean Lake
Midwest
Wollaston
Lake
Cigar Lake
McArthur River
Rabbit Lake
ALBERTA
SASKATCHEWAN
Key Lake
N
COGEMA
Resources Inc.

Figure 1


COGEMA
Resources Inc.
CLUFF MINING
GENERAL LAYOUT
MINING AREA
OREBODIES
MINED OUT
BEING MINED
OTHERS
PROPOSED DOMINIQUE-JANINE EXTENSION PROJECT
AIRSTRIP
CLAUDE LAKE
CLAUDE
DOMINIQUE PETER
DOMINIQUE JANINE
OP
D
N
DOMINIQUE JANINE EXT.
EFFLUENT MANAGEMENT AREA
TAILINGS POND
SNAKE LAKE
MILL AREA
ISLAND LAKE
CLUFF LAKE
SOUTHGATE
ROAD TO SASKATOON
RESIDENTIAL AREA
CERMAINE LAKE
N
0
1
2 Km.
D' - SEPT., 1994
9463-700

ure 2

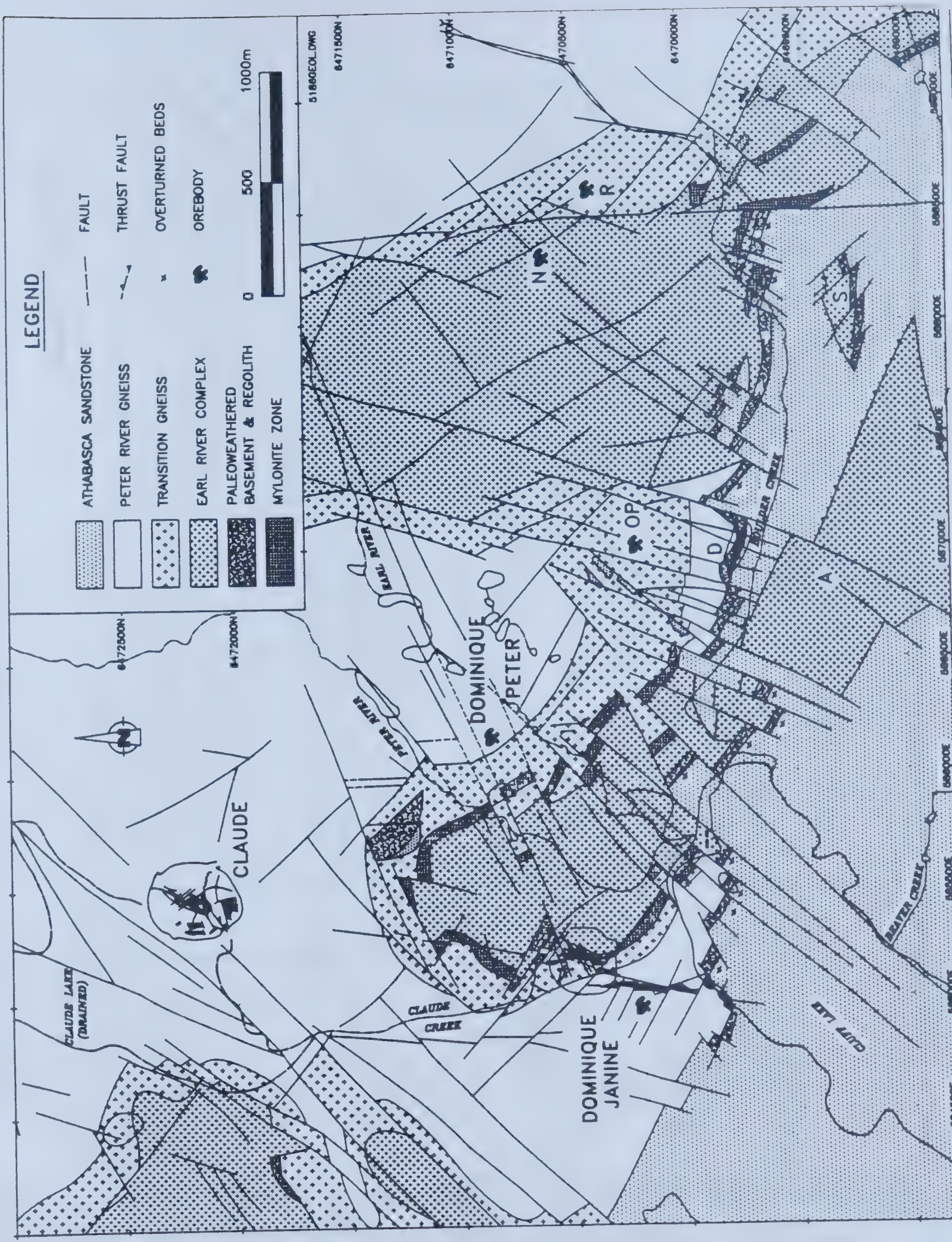
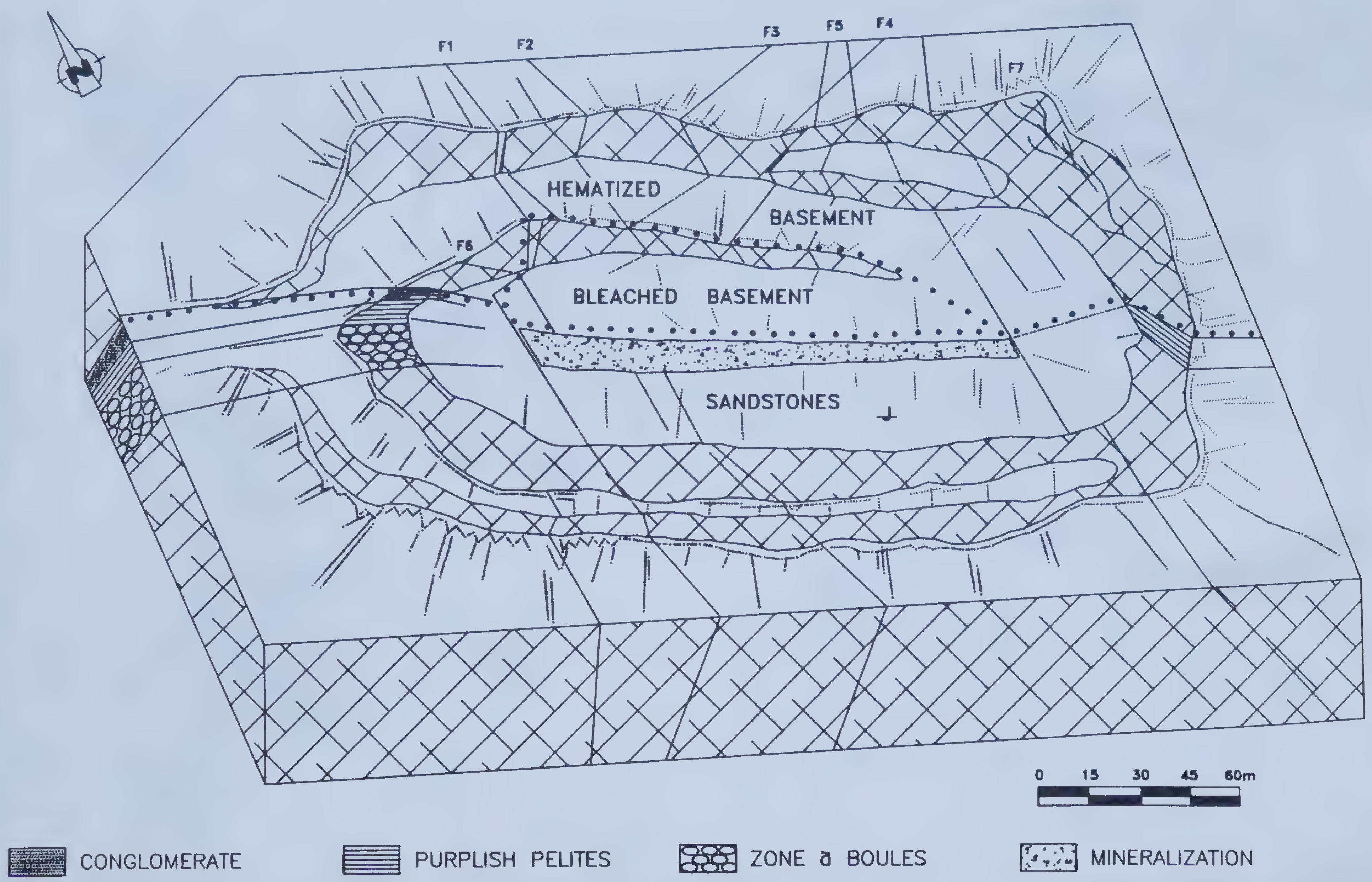

LEGEND
ATHABASCA SANDSTONE
PETER RIVER GNEISS
TRANSITION GNEISS
EARL RIVER COMPLEX
PALEOWEATHERED BASEMENT & REGOLITH
MYLONITE ZONE
FAULT
THRUST FAULT
OVERTURNED BEDS
OREBODY
0
500
1000m
5186GEOL.DWG
6471500N
6471000N
6470500N
6470000N
6469500N
6472500N
6472000N
N
CLAUDE
CLAUDE LAKE (DRAINED)
CLAUDE CREEK
PETER RIVER
EARL RIVER
DOMINIQUE
PETER
DOMINIQUE JANINE
OP
D
A
N
R
S
BOULDER CREEK
BEAVER CREEK
CLUFF LAKE
584500E
585000E
585500E
586000E
586500E
587000E
587500E
588000E
588500E
589000E

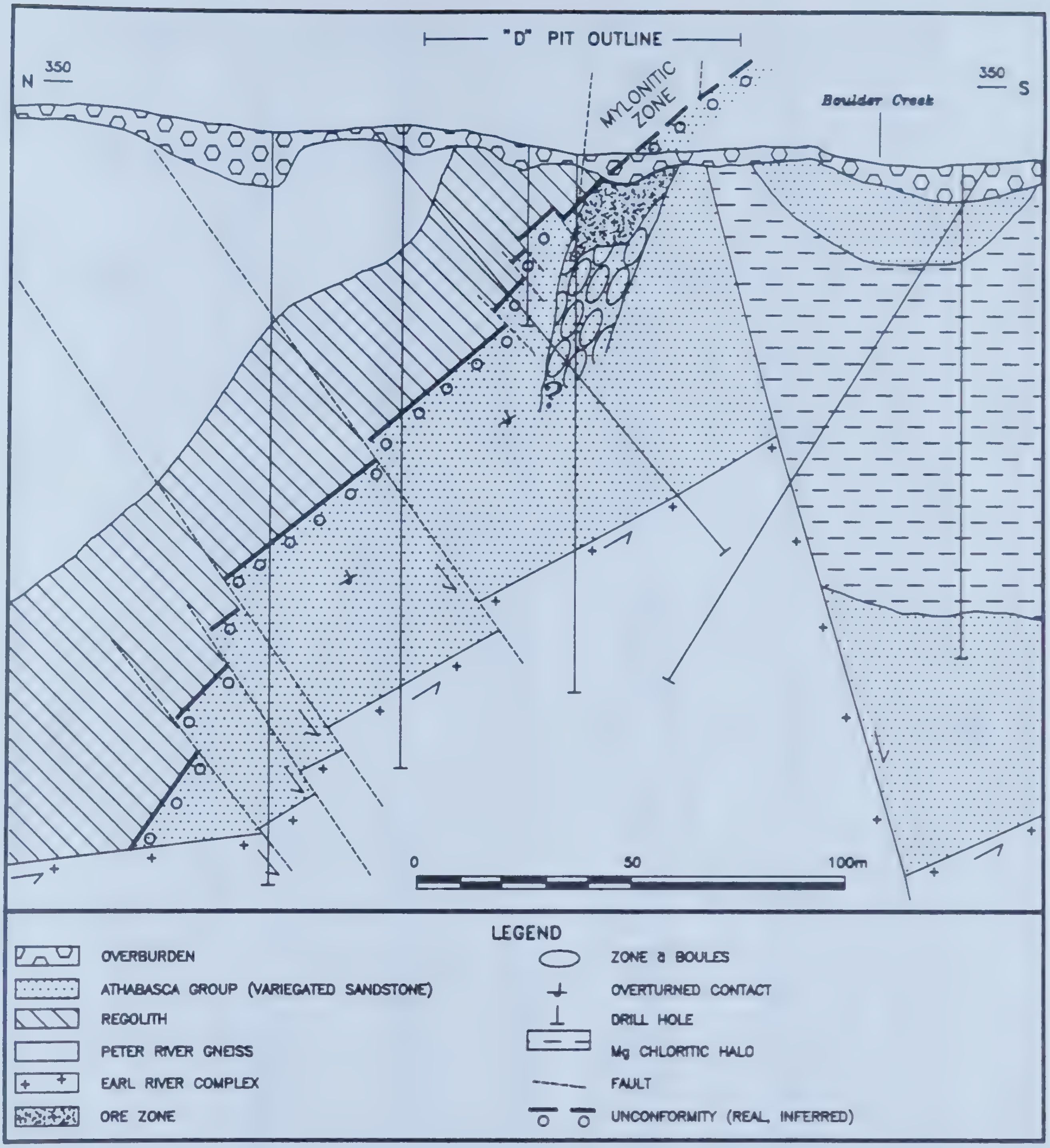
Figure 3 GEOLOGY OF MINERAL LEASE 5186


F1
F2
F3
F5
F4
F7
F6
HEMATIZED
BASEMENT
BLEACHED BASEMENT
SANDSTONES
0
15
30
45
60m
CONGLOMERATE
PURPLISH PELITES
ZONE a BOULES
MINERALIZATION

Major lithostructural units in the D open pit at the 323m mining level (walls are hatched, horizontal surfaces are in white).

Figu

c\r1 ?\DISPLAY\DPIT71.DW


"D" PIT OUTLINE
N 350
350 S
MYLONITIC ZONE
Boulder Creek
?
0
50
100m
LEGEND
OVERBURDEN
ATHABASCA GROUP (VARIEGATED SANDSTONE)
REGOLITH
PETER RIVER GNEISS
EARL RIVER COMPLEX
ORE ZONE
ZONE a BOULES
OVERTURNED CONTACT
DRILL HOLE
Mg CHLORITIC HALO
FAULT
UNCONFORMITY (REAL, INFERRED)

N–S cross section through the D open pit, showing alteration haloes and tectonic features (modified from Ey et al., 1982).

Figure 5

C:\DRAWING\DISPLAY\DPITF11.DWC

Figure 6

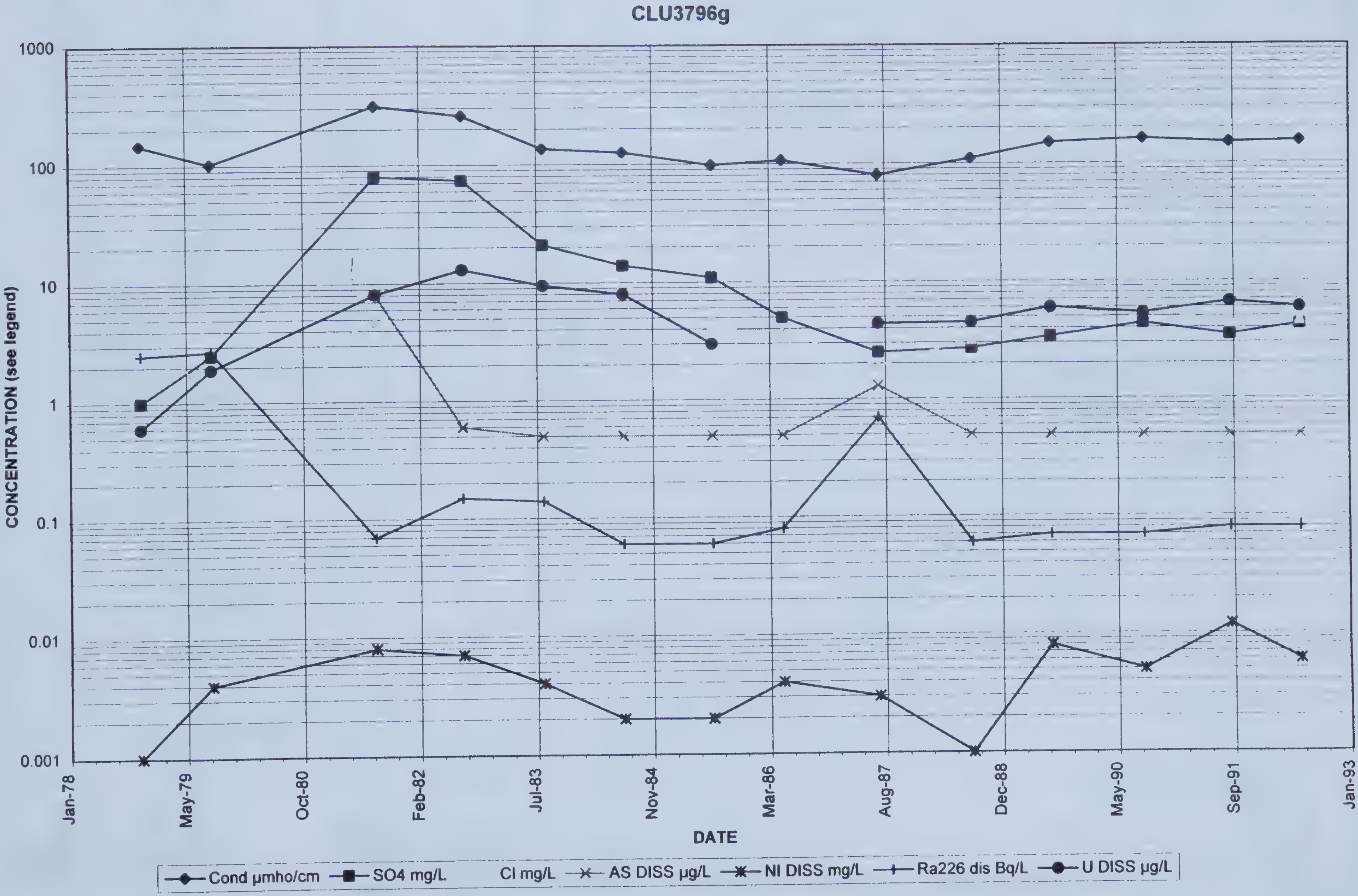

CLU3796g
CONCENTRATION (see legend)
1000
100
10
1
0.1
0.01
0.001
Jan-78
May-79
Oct-80
Feb-82
Jul-83
Nov-84
Mar-86
Aug-87
Dec-88
May-90
Sep-91
Jan-93
DATE
Cond µmho/cm
SO4 mg/L
Cl mg/L
AS DISS µg/L
NI DISS mg/L
Ra226 dis Bq/L
U DISS µg/L

Figure 7

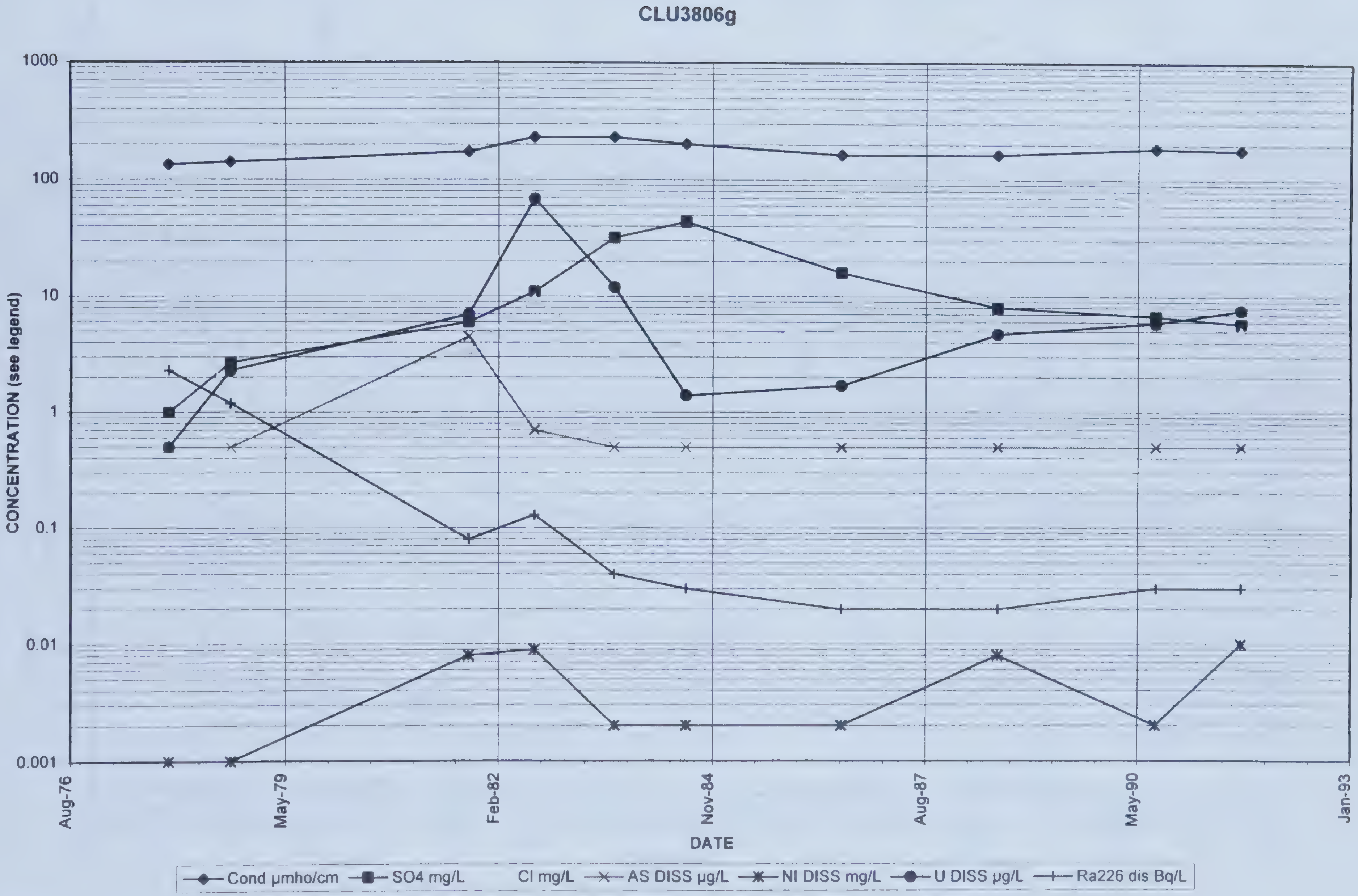

CLU3806g
CONCENTRATION (see legend)
1000
100
10
1
0.1
0.01
0.001
Aug-76
May-79
Feb-82
Nov-84
Aug-87
May-90
Jan-93
DATE
Cond µmho/cm
SO4 mg/L
Cl mg/L
AS DISS µg/L
NI DISS mg/L
U DISS µg/L
Ra226 dis Bq/L

Figure 8

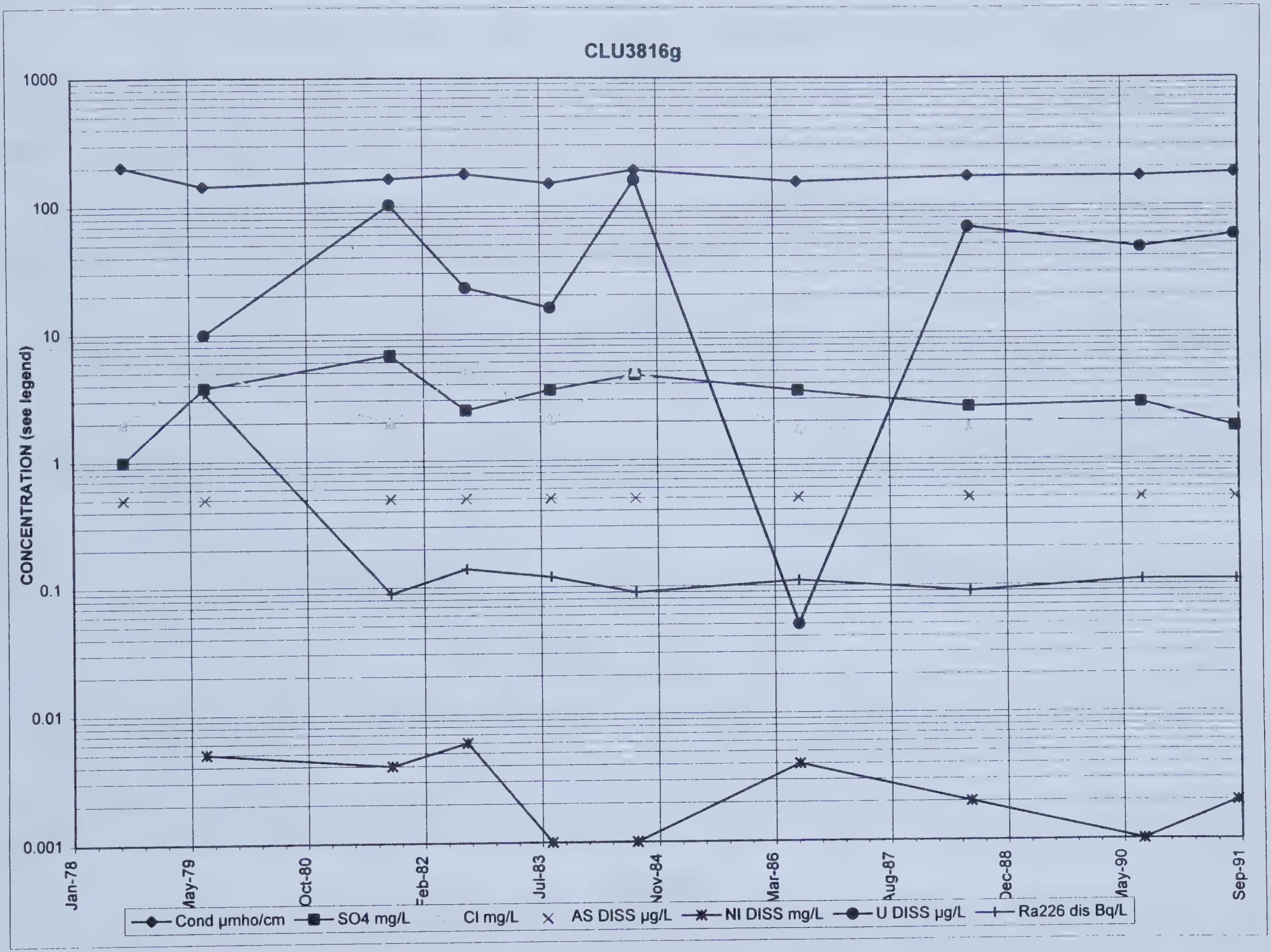

CLU3816g
CONCENTRATION (see legend)
1000
100
10
1
0.1
0.01
0.001
Jan-78
May-79
Oct-80
Feb-82
Jul-83
Nov-84
Mar-86
Aug-87
Dec-88
May-90
Sep-91
Cond µmho/cm
SO4 mg/L
Cl mg/L
AS DISS µg/L
NI DISS mg/L
U DISS µg/L
Ra226 dis Bq/L

Figure 9

Boulder Creek Upstream of D-Pit

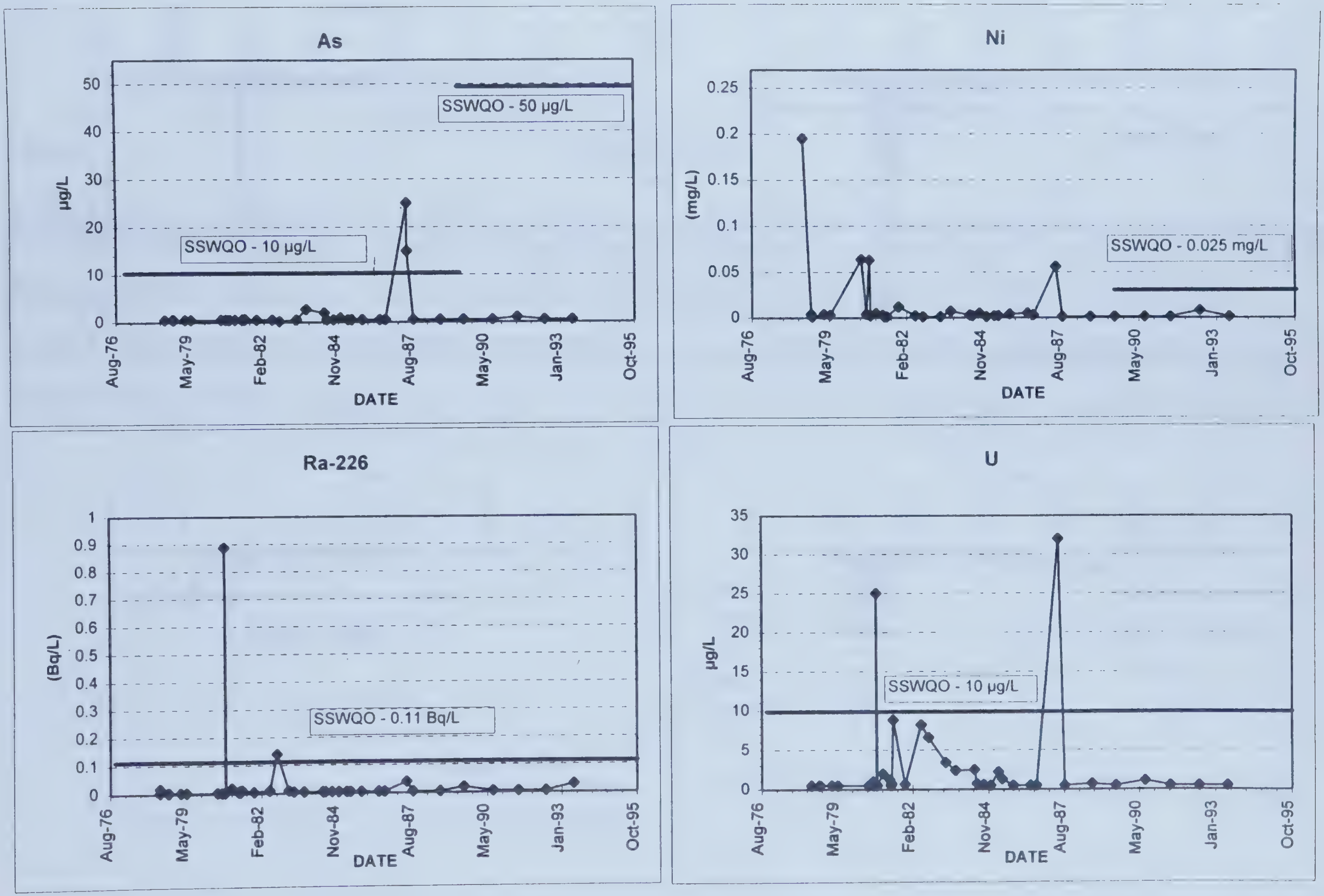


Figure 10

Boulder Creek at Cluff Lake

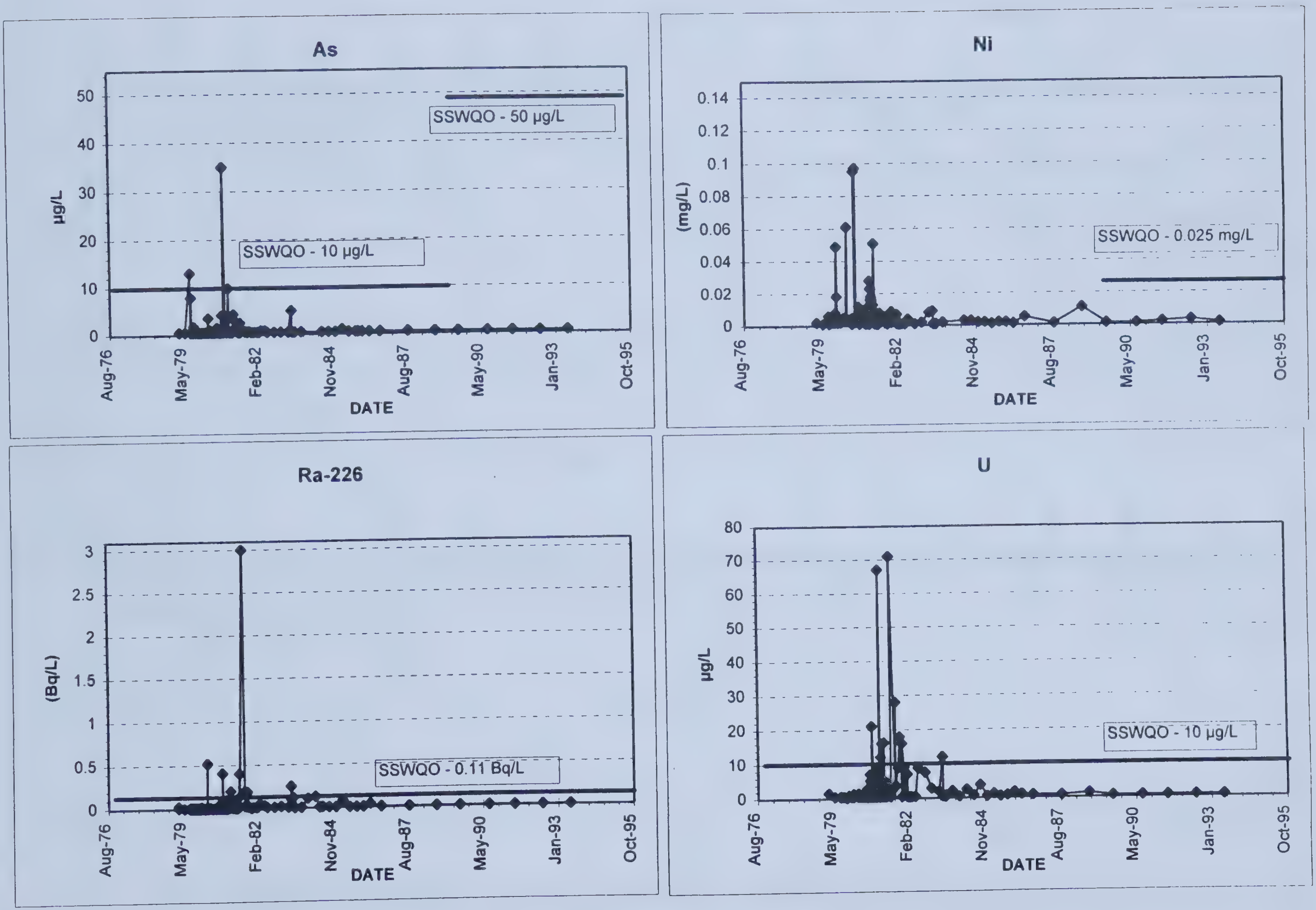


Figure 11

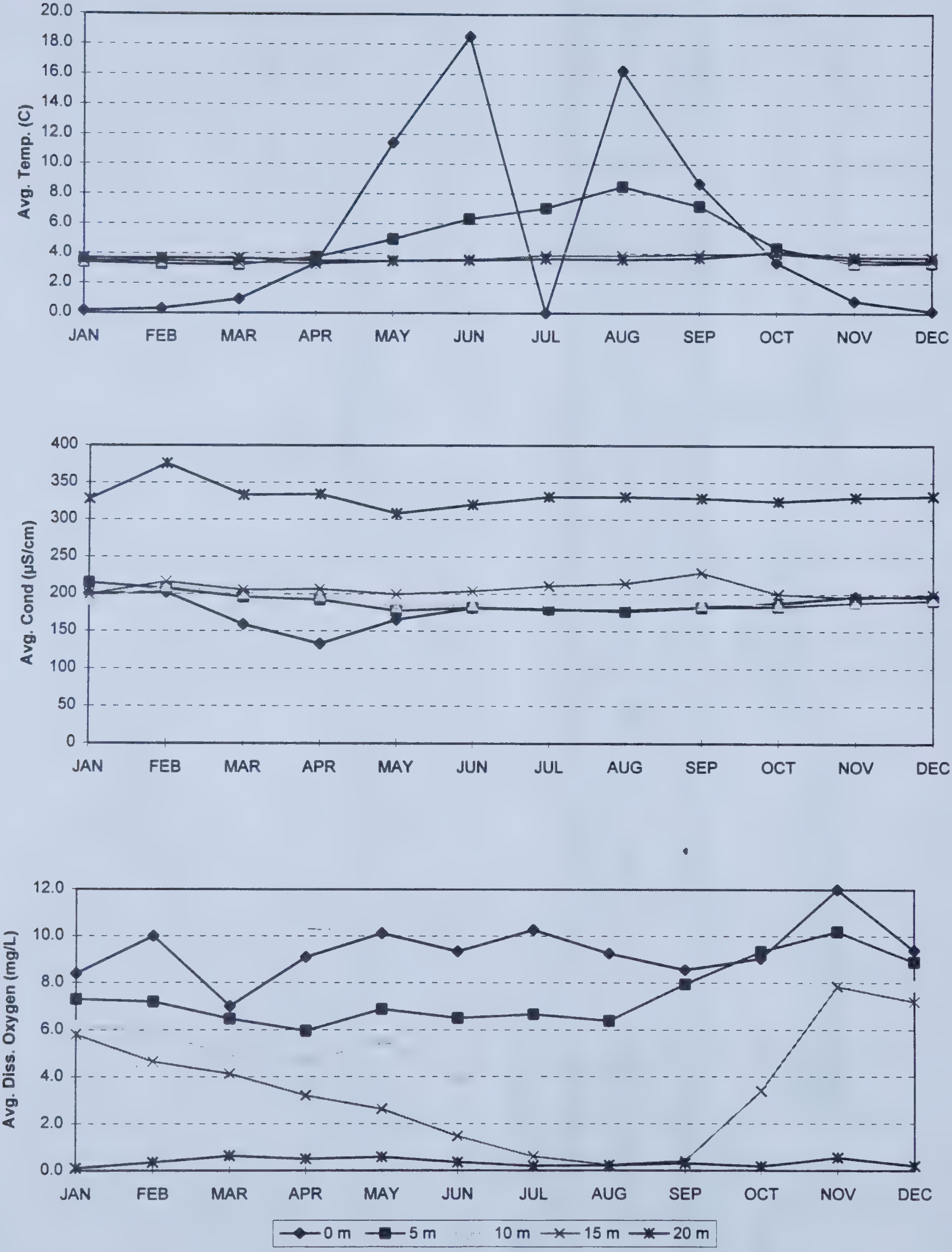
CLUFF MINING
WEATHER DATA
1995

Temperature - Celsius	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Y-T-D
Normal *, Avg Mean Temp	-19.6	-15.9	-8.8	0.6	9.2	14.7	16.8	15.8	8.8	1.1	-11.0	-18.0	-0.5
Normal *, Avg precipitation	18.6	17.1	21.5	17.0	27.4	53.8	82.0	70.5	42.0	36.7	29.2	20.4	427.6

* Normal - average since 1981

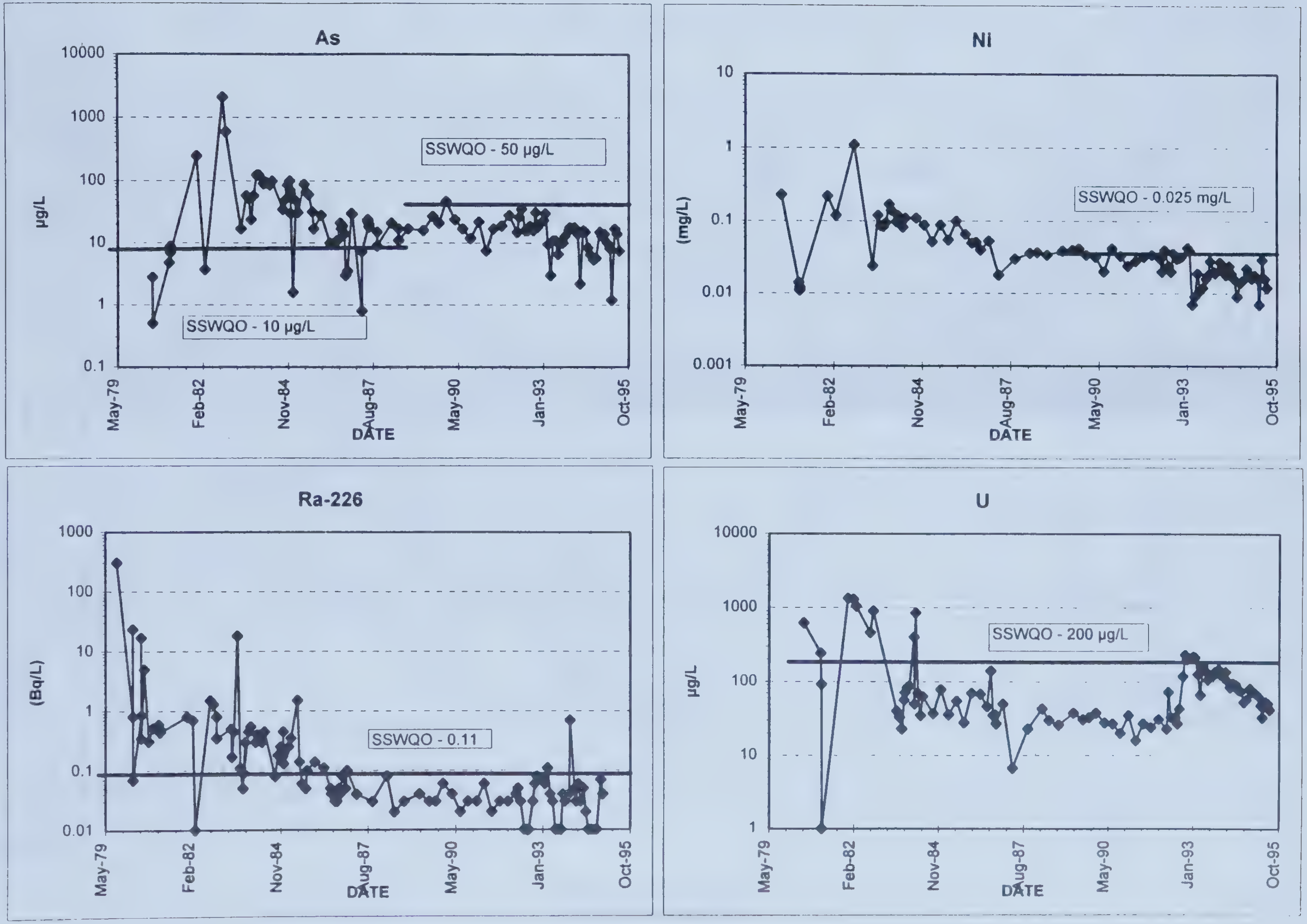
D-PIT FIELD MEASUREMENTS
Average By Month - Apr.1992 to Aug. 1995

Figure 12



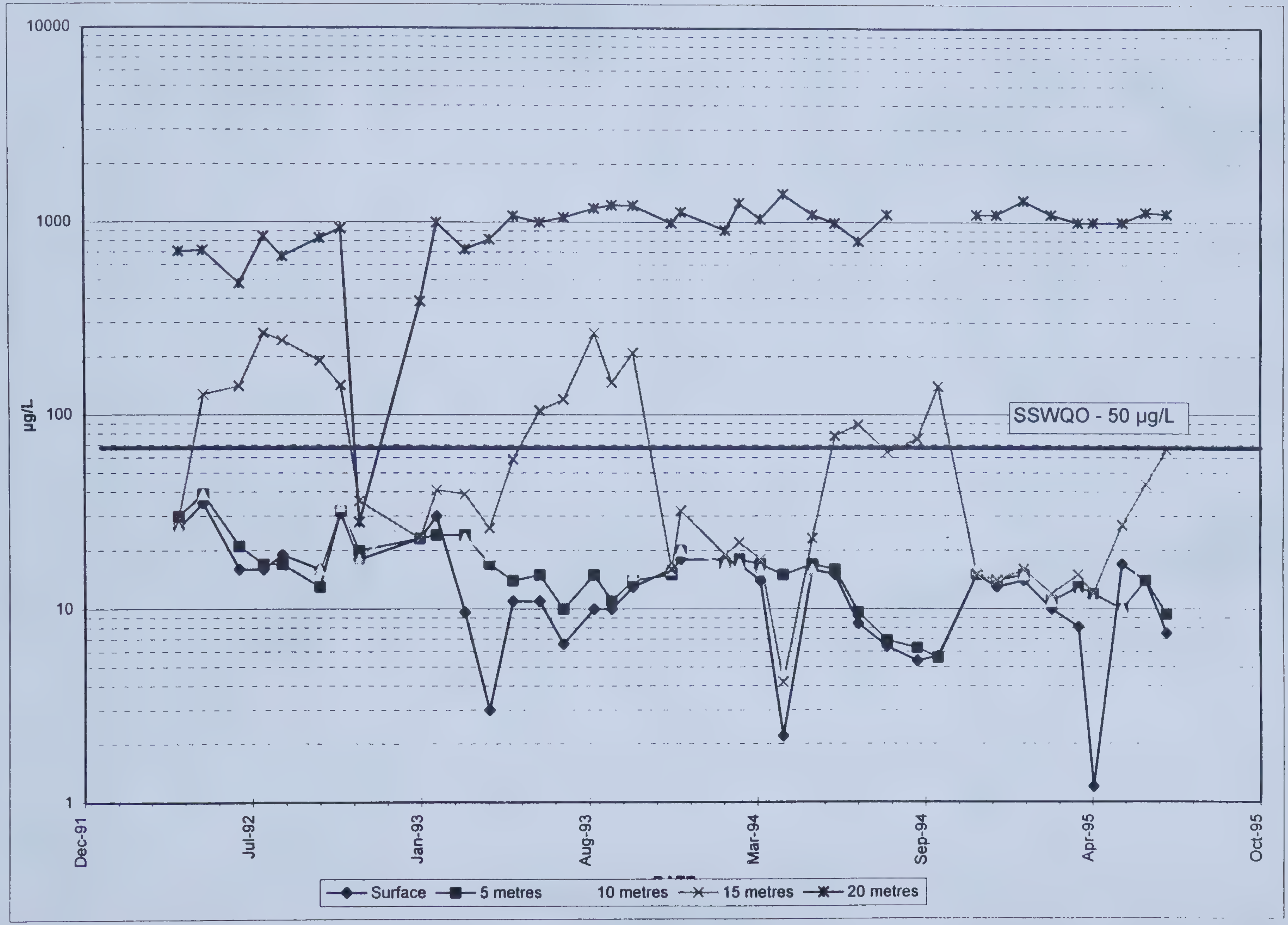
D-Pit Surface Water
Historical Summary - Selected Parameters

Figure 13



Arsenic Concentration
April 1992 to July 1995

Figure 14



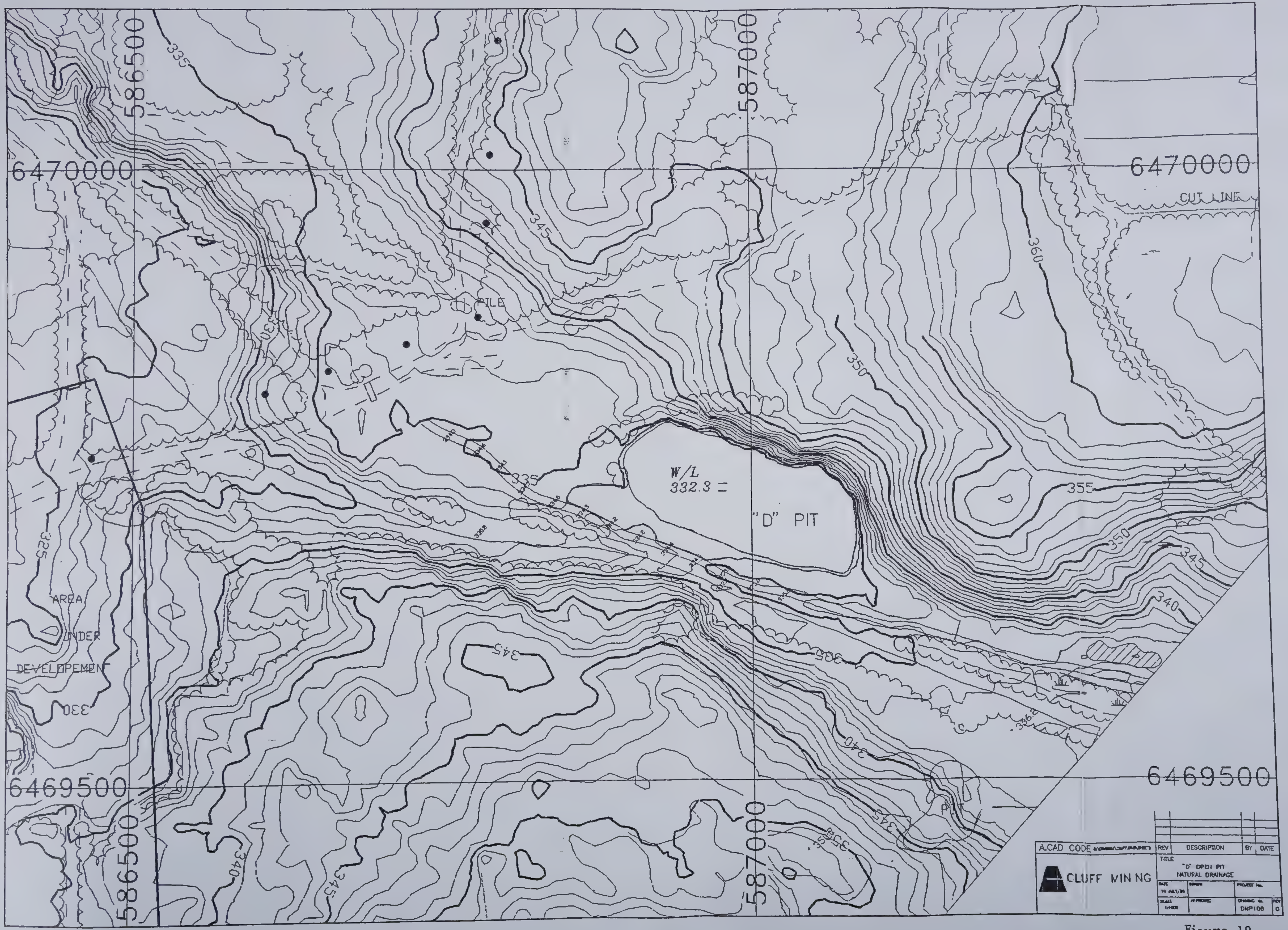

586500
587000
6470000
6469500
CUT LINE
PILE
W/L
332.3
"D" PIT
AREA
UNDER
DEVELOPEMENT
PIT
325
330
335
340
345
350
355
360
336.2
A.CAD CODE
REV
DESCRIPTION
BY
DATE
CLUFF MINING
TITLE
"D" OPEN PIT
NATURAL DRAINAGE
DATE
10 JULY/90
PROJECT No.
SCALE
1:1000
APPROVED
DRAWING No.
DNP106
REV
0

Figure 19

Figure 15

Nickel Concentration
April 1992 to July 1995

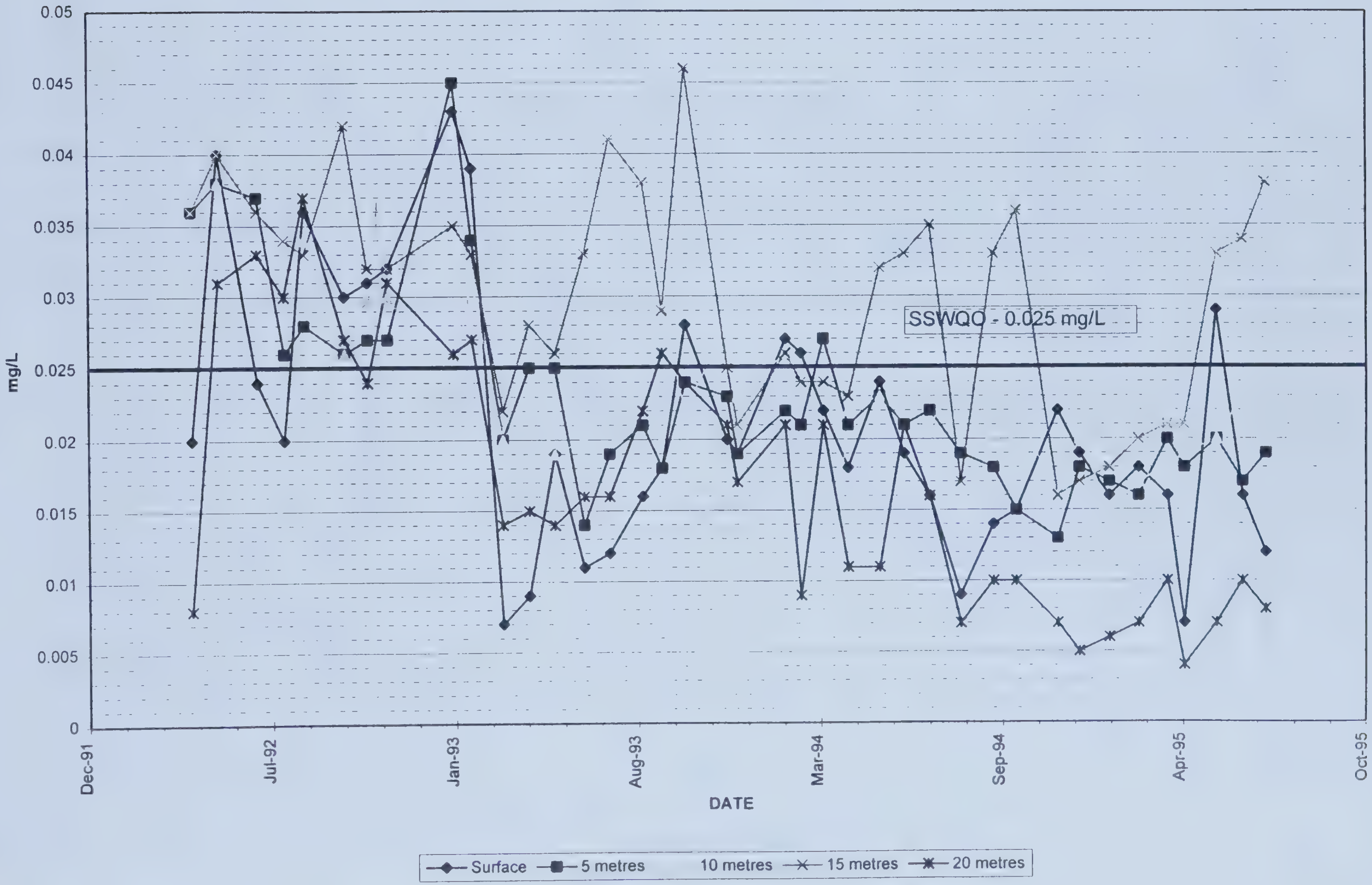
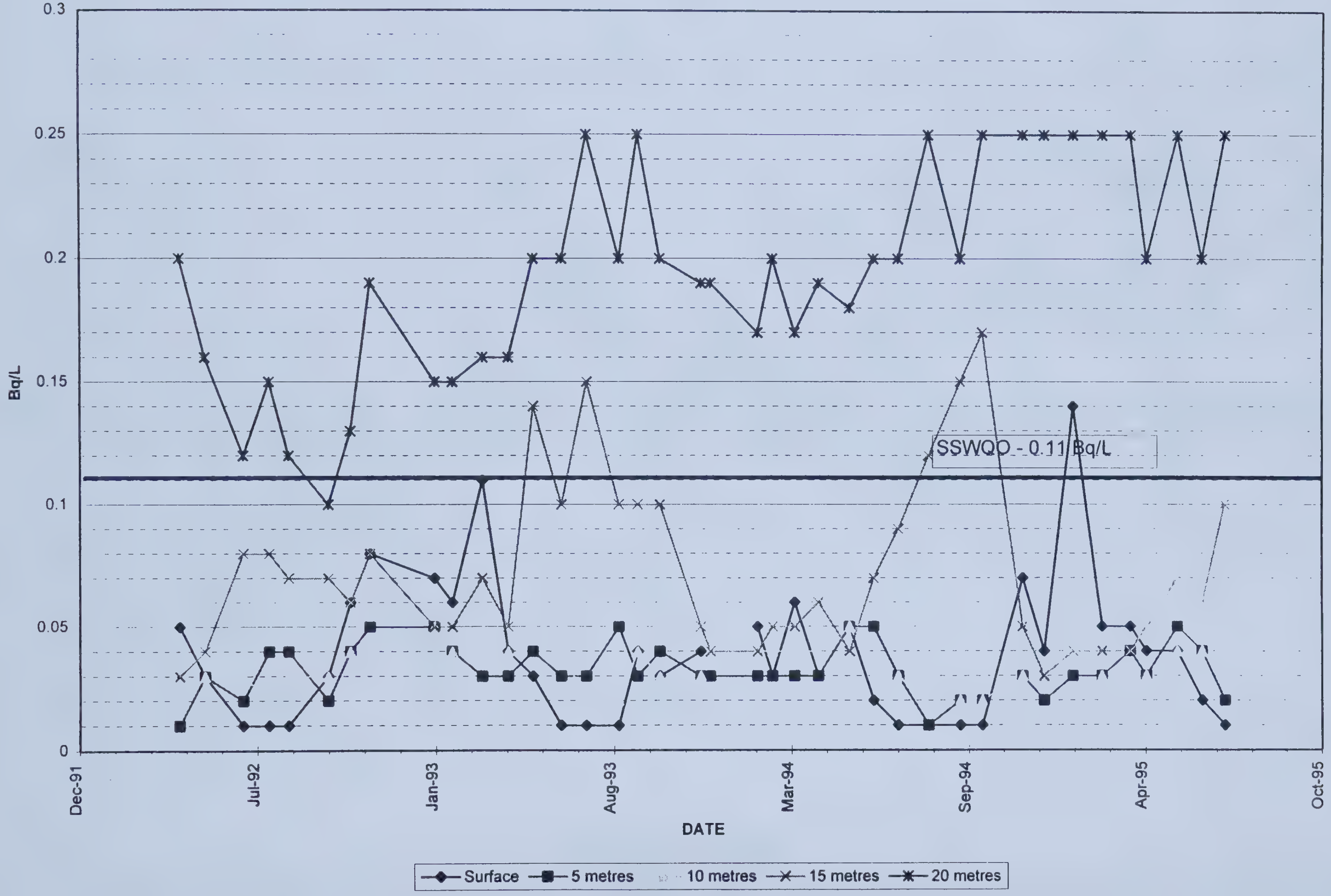


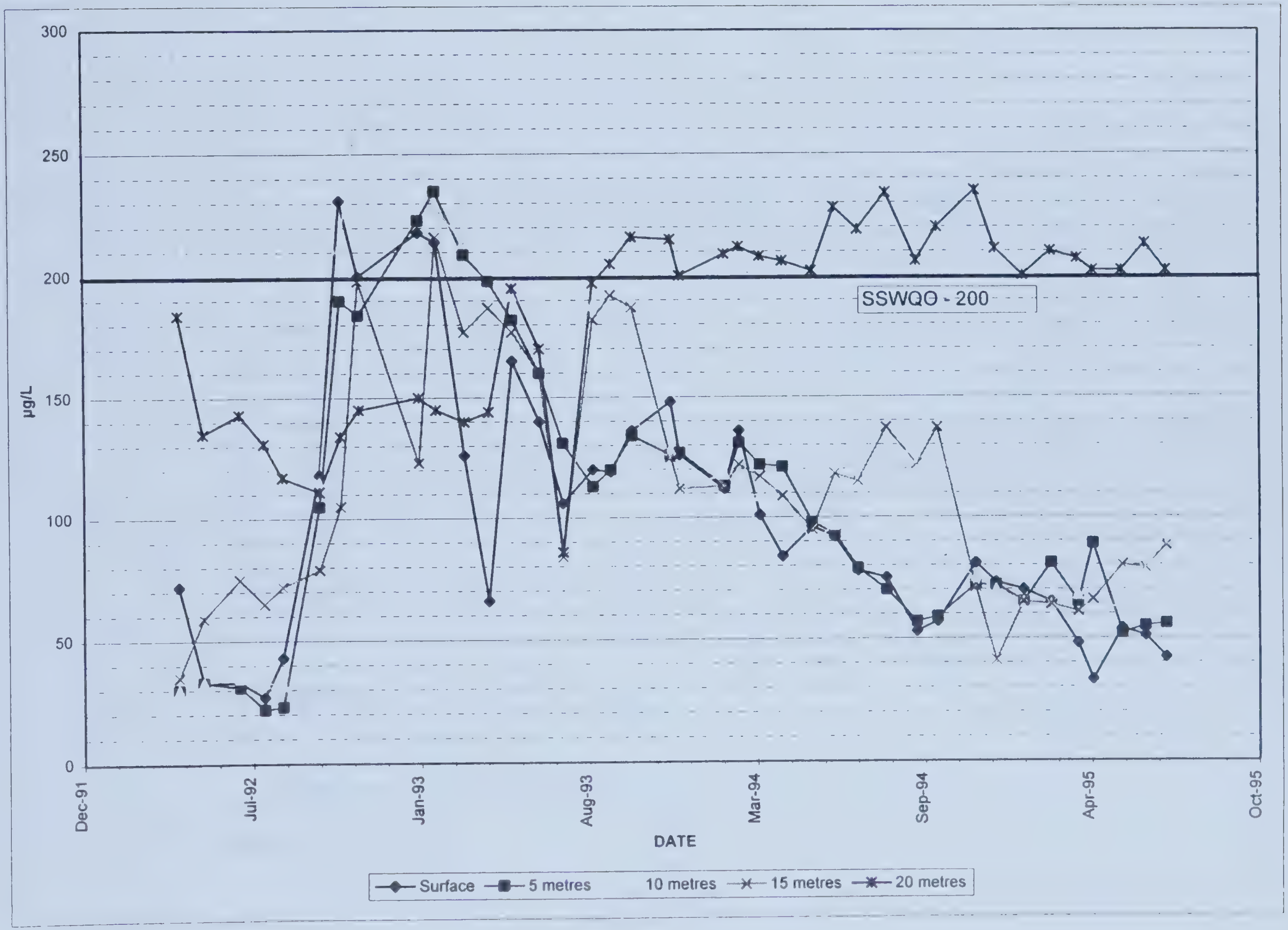
Figure 16

Radium-226 Concentration
April 1992 to July 1995



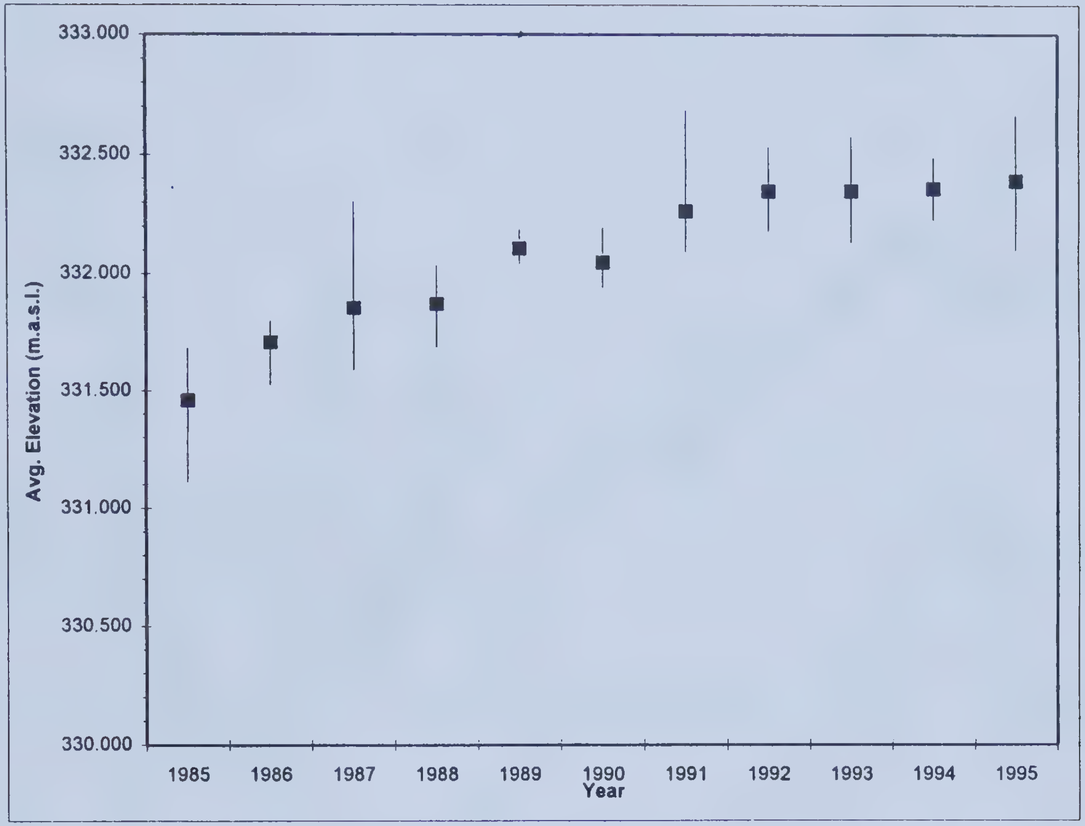
Uranium Concentration
April 1992 to July 1995

Figure 17



D-Pit Water Elevation
1985 to 1995

Figure 18



Natural analogs for sustainable reclamation landscape design at Syncrude

Marie-José Keys
CoSyn Technology for Syncrude Canada Ltd.
P.O. Bag 4009
Ft McMurray, AB
T9H 3L1

Gord McKenna
Syncrude Canada Ltd.
Edmonton Research Centre
9421 - 17 Ave
Edmonton, AB
T6N 1H4

Les Sawatsky
Agra Earth and Environmental Ltd.
221 - 18th St. S.E.
Calgary, AB
T2E 6J5

Terry van Meer
Syncrude Canada Ltd.
P.O. Bag 4009
Ft McMurray, AB
T9H 3L1

Abstract

Syncrude Canada Ltd is committed to providing a biologically self-sustaining, geotechnically stable, and maintenance free lease-abandonment landscape that has a productive capability at or above the predisturbance level, and erodes in harmony with the regional landscape. A philosophy being used in the design is that of creating a robust, mature landscape, that is, one which closely mimics geomorphologically mature features of the regional landscape. Such a landscape will have slow, relatively controlled erosion, and an inherent landform stability. The most significant aspect to long-term stability is control of the fluvial geomorphology of the reclaimed landscape.

In providing designs to be stable for hundreds or thousands of years, new approaches are required. For instance, designs must incorporate information from the study of local and regional landforms and landscape features using natural analogs and assessment of natural erosion rates. As well, long-term riprap durability becomes a greater issue, the effects of wildlife (and in particular beaver dams) and climatic change on the landscape must be considered, and an integrated hydrological, geotechnical, geomorphological, and biological approach must be used.

Introduction

Syncrude Canada Ltd. operates a large integrated Oil Sands surface mine and oil production facility at Mildred Lake, Alberta, approximately 40 km north of Fort McMurray (Figure 1). Syncrude's agreement for developing its Oil Sands Leases 17 and 22 includes commitment to provide a productive, self-sustaining, lease-closure landscape that is geotechnically stable and which evolves through geologic time in harmony with the regional landscape.[1]

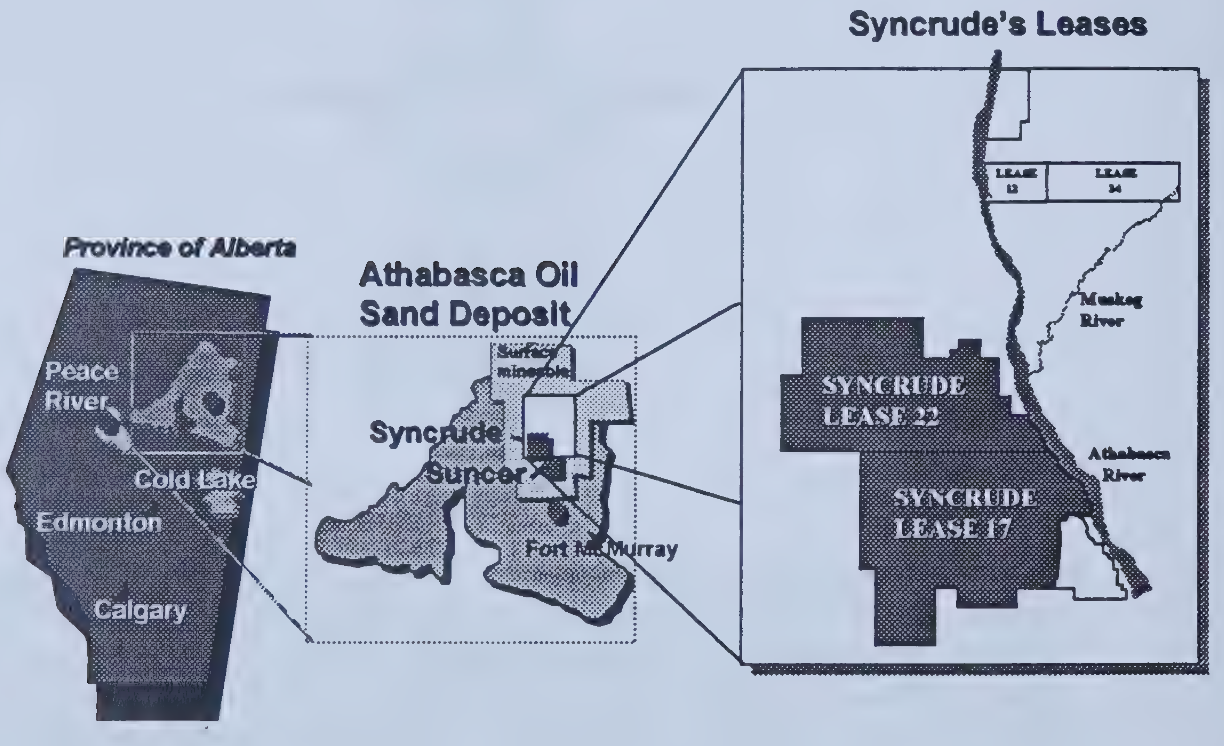

Syncrude's Leases
Province of Alberta
Peace River
Cold Lake
Edmonton
Calgary
Athabasca Oil Sand Deposit
Surface mineable
Syncrude
Suncor
Fort McMurray
LEASE 12
LEASE 34
Muskeg River
SYNCRUDE LEASE 22
Athabasca River
SYNCRUDE LEASE 17

Figure 1
Location Plan

Traditionally, most mine designs have been largely dominated by production economics and geotechnical issues. Lease-closure issues have been relegated to the final years of production. More recently, greater attention has been placed on environmental issues related to lease-closure and incorporation of these issues in lease design before and during lease operation. Closure designs should include "preservation and protection of appropriate cultural, recreational, scenic, historic, and ecological values; control of erosion, slides, flooding and pollution of water;... prevention of hazards to public health and safety; achieving harmony with the surrounding landscape; determining the best long-term use of the land so that restoration can be designed toward an appropriate end use."[2]

Some design criteria, by regulating agencies, may not be appropriate to create a sustainable lease-closure reclamation landscape. Instead, the landscape should be designed to mimic the natural one. Several philosophies have recently been developed to guide reclamation design including:

- creating a geomorphologically mature reclamation landscape
- creating a robust landscape — one which improves in stability with time
- creating a landscape which mimics natural systems in the area
- using best available demonstrated control technology (BADCT)[3] to insure best landscape design and construction to reduce long-term liabilities
- invoking a design-for-closure philosophy in which mine and tailings designers and planners work together with reclamation specialists to develop a sustainable final landscape

Adoption of a suitable design-for-closure plan is needed to ensure that the reclamation landscape will be maintenance free. The reclamation area of 18,000 ha is very large. It will contain erodible tailing sand deposits, lakes of fine tails (clay/fines water emulsion - 30% solids by weight) capped with water, 40 km of first order constructed streams, 200 km of second and third order streams, vertical relief of 200 m, and some slopes steeper than typically found in upland areas of the natural landscape. To ensure that these elements can work together in a sustainable landscape, careful planning and construction are required. In some cases, mine designs must be altered to fit the final landscape plans. This approach, presently being applied at Syncrude, requires considerable involvement from specialists in a variety of fields.

Regional setting

Syncrude Leases 17 and 22 are in the mid-boreal mixed wood ecoregion dominated by aspen and black spruce, with frequent white spruce stands and bogs. The area is flat to gently rolling with broad gentle uplands and deeply incised meandering rivers. Much of the upland area is heavily populated by beavers which generally have a moderating influence on creek-flows, natural erosion, and sediment yields. In muskeg areas, very little overland flow has been observed as it has been found that most of the flow occurs as seepage through the muskeg. The large storage capacity of the muskeg results in attenuation of peak flows except when partially frozen.

The climate is temperate continental with long, cold winters and short, warm summers. During the winter, there is about 150 mm (water equivalent) of snowfall and rivers and creeks are covered with ice from about November until May. The mean annual precipitation at the Syncrude site is about 460 mm with about 75% of this precipitation returned by evapotranspiration, the remaining as runoff. Analysis of recent climatic and streamflow data shows that peak flows from all but the largest watersheds are controlled by intense summer rainstorms rather than by snowmelt events.

The bedrock geology of the Athabasca Oil Sands area has been described by many including Mossop[4]. Devonian limestone outcrops are found along both the MacKay and Athabasca rivers. The limestone is overlain by Cretaceous McMurray Formation (Athabasca Oil Sand) which is in turn overlain by Cretaceous Clearwater Formation marine clays and silts. Occasional 80-500 mm thick indurated "siltstone" layers are present in these Clearwater clays. The formations are generally flat-lying and continuous except where locally eroded by glacial or fluvial processes.

The surficial geology west of the Athabasca River, more specifically, at the Syncrude site, consists of thin Quaternary sediments such as glacial till, overlain by glaciofluvial sands, gravels, glaciolacustrine silts and clays as presented by Bayrock[5]. Much thicker Quaternary sequences cover uplands to the east and west[6]. The difference between these thicknesses is partially due to the Laurentide ice sheet retreating northward approximately ten thousand five hundred years before present (10.5 ka BP) depositing on-lap glaciolacustrine deposits and a paleoflood, 9.9 ka BP, scouring the low lying area around the Syncrude site. Locally there are Holocene alluvial and lake deposits and landslide colluvium. As mentioned above, extensive muskeg, up to 5 m thick, typifies much of the area.

The area east of the Athabasca River has markedly different surficial geology. The surficial soil is sand with occasional boulders and contains virtually no fines. This extensive sandy deposit is thought to be lodgment till or glacially overridden outwash deposits. Paleowind patterns have created sheet and dune deposits by reworking the sand. The resulting vegetation is much different in that jackpine is much more common, the forests are generally more open, spruce still fills most of the bogs, and large muskeg and organic areas are less common. Thus the character of the landscape is greatly affected by the surficial geology.

Syncrude Leases 17 and 22 include three significant watersheds including the MacKay River, Beaver River and Poplar Creek, and numerous small tributary creeks. To facilitate mining, the Beaver River was diverted in the mid 1970's into Poplar creek, and creeks that once flowed into the Beaver River are now intercepted and rerouted around the mine area (Figure 2). All other waters that either originate as runoff from disturbed areas, or are imported for use in the plant, are contained on site and recycled.

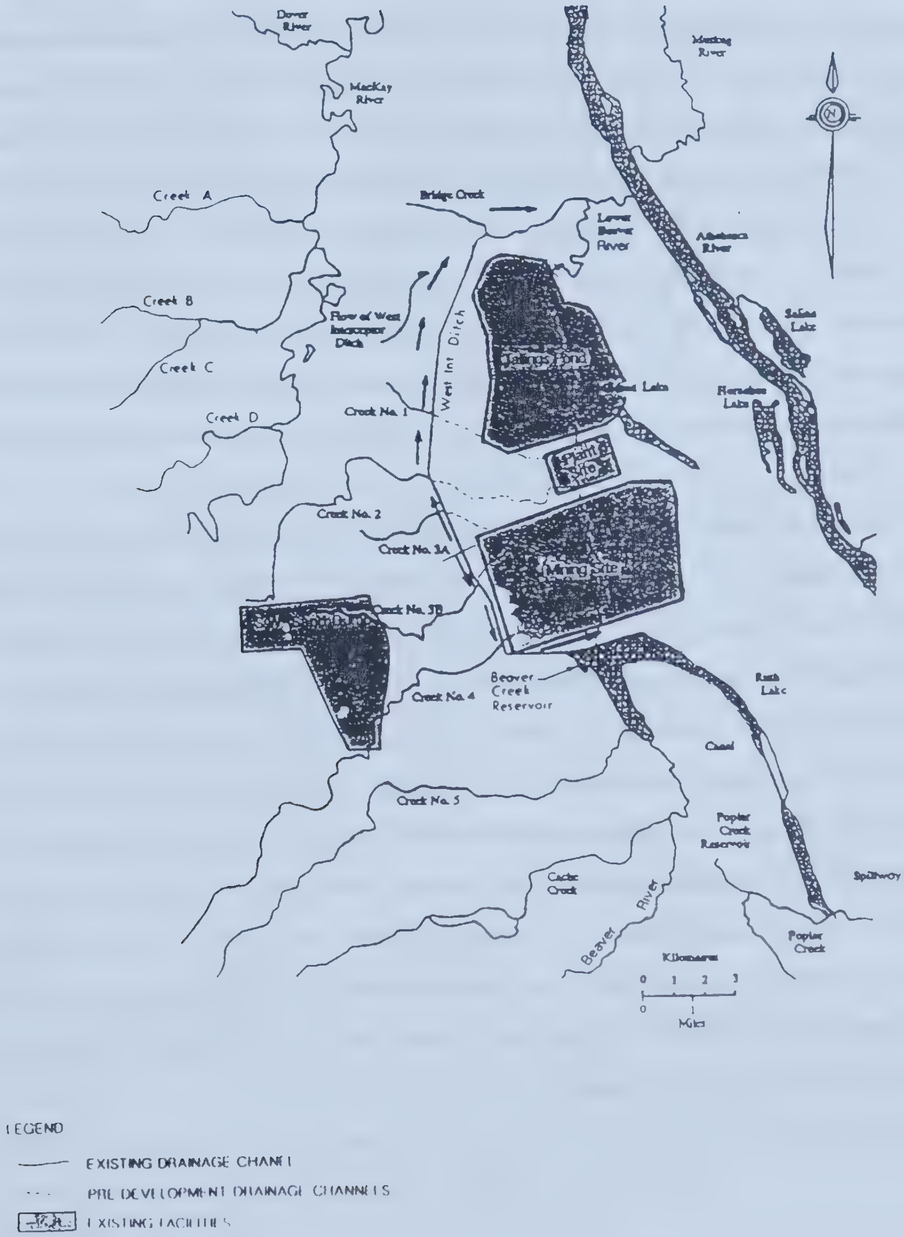

Dover River
MacKay River
Muskeg River
Creek A
Bridge Creek
Lower Beaver River
Athabasca River
Creek B
Flow of West Interceptor Ditch
West Interceptor Ditch
Saline Lake
Creek C
Tailings Pond
Mildred Lake
Horseshoe Lake
Creek D
Creek No. 1
Plant Site
Creek No. 2
Creek No. 3A
Mining Site
Creek No. 3B
Beaver Creek Reservoir
Creek No. 4
Ruth Lake
Canal
Creek No. 5
Poplar Creek Reservoir
Spillway
Cache Creek
Beaver River
Poplar Creek
Kilometres
0 1 2 3
0 1
Miles
LEGEND
EXISTING DRAINAGE CHANEL
PRE DEVELOPMENT DRAINAGE CHANNELS
EXISTING FACILITIES

Figure 2- Beaver River Diversion around Syncrude's mine site.

Long-term design issues

In 1992, Syncrude began working on major drainage system alternatives for lease-closure based on the premise that the closure landscape would be maintenance-free. Some areas of risk were recognized and, as a result, studies were initiated, mostly in the areas of natural stream hydraulics and geomorphology, and regional hydrology. These studies are discussed in more detail later.

A geotechnical hazard assessment was conducted on various landscape alternatives and proved to be enlightening. One of the resulting philosophies being discussed is to adopt the "Best Available Design Control Technology" (BADCT)[7] in which designs are advanced to the best possible state with existing technology. Under this philosophy, each of the identified risk areas are investigated to a reasonable and practical level and the residual risks to the landscape are described as necessary. New risks may occur with time that were not foreseen in design and it must be assumed that natural replication will mitigate or reduce these risks. Such an example was recently observed on one of Syncrude's tailings structures. Pingo-like ice mounds where formed on a reclamation bench due to freezing of artesian seeps from the active structure[8].

For large reclaimed landscapes designed to be self-sustaining for hundreds to thousands of years, systems must be included that are adaptable to major rainstorms, fires, droughts, wind-storms, wildlife and human interference, climate change, and unfavorable combinations of these events. It is well known that steep unarmored slopes will flatten, planar slopes will gully, straight rivers will start to meander, immature convex-up reaches will become concave-up, lakes will infill and forest soils will undergo succession. Unplanned, rapid changes in the reclaimed landscape are not desirable. Such rapid changes could result in unacceptably high sediment loading of streams, gully scarring, and landslides. Instead, it is preferable to create a mature landscape, upon mine closure, so that the expected rate of change will be comparable to that of the reclaimed landscape in geologic time. Previous criteria for reclamation involving design recurrence intervals seem less appropriate than the design philosophy to build a robust and mature landscape by documenting and learning from natural analogs.

Streams and Rivers

Important natural analogs being studied are the natural streams and rivers of the area. Surface runoff, leading to major streams and rivers are the root of many hazards associated with the long term sustainability of the reclaimed landscape. It is imperative that the reclaimed, man-made streams flow into natural ones without jeopardizing the geotechnical stability of the lease-closure landscape. To provide continuity, these man-made streams must mimic the natural, more mature ones in the area. Otherwise these streams will be subject to excessive erosion in order to attain stability. Previous regulations that have required erosion protection and water conveyance structures to be designed for probable maximum floods (PMF), or a flood of a specific recurrence interval, may not be appropriate for designing a maintenance-free landscape. Designing based on natural analogs does not necessarily involve recurrence interval but rather mimics natural systems which may erode slowly during extreme events. The magnitude of 100-year and 1000-year events would be still considered in the design but only as guides to predicting long-term erosion rates.

Natural analogs have been documented by fluvial geomorphologists who have studied rivers worldwide and developed relationships between stream-flow rates, sinuosity, bed material, depth-to-width ratios, and slope. A reclamation design team has the ability to change most of these variables and can use published results to estimate stable regimes for all of these variables. Natural systems in the area allow verification of the applicability of the published regime relationships to the boreal forest area of Northeastern Alberta. Locally, two studies have been undertaken to determine properties of streams and rivers affecting Leases 17 and 22.

The first study involved examination of erosion rates and fluvial processes of existing natural streams on the Syncrude leases. Longitudinal stream profiles were created and results were documented. Most of these studies were based on existing contoured orthophotographs and knowledge of other Alberta rivers and creeks. It was found that most existing creeks and rivers are stable and unlikely to change significantly. Any stream which encounters the Athabasca River valley wall is subject to very slow degradation. The MacKay River, for example, is widening its valley at rates of about 2 m per century and downcutting about 0.2 m per century[9] (Figure 3). The lower reaches of this river may be considered to be geomorphologically immature as shown by the immature convex-up reaches of MacKay River (Figure 4).

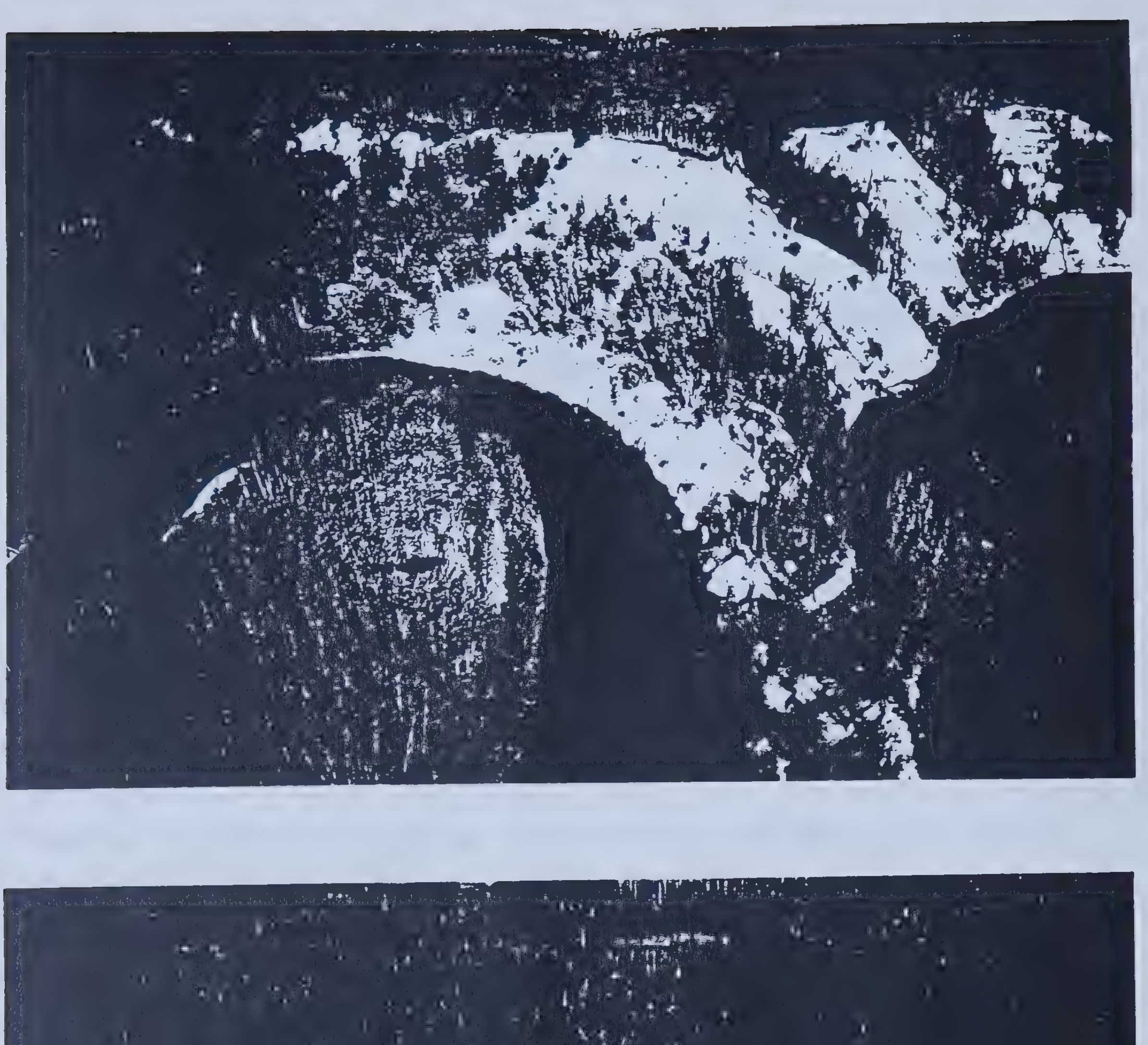


Figure 3 - MacKay River

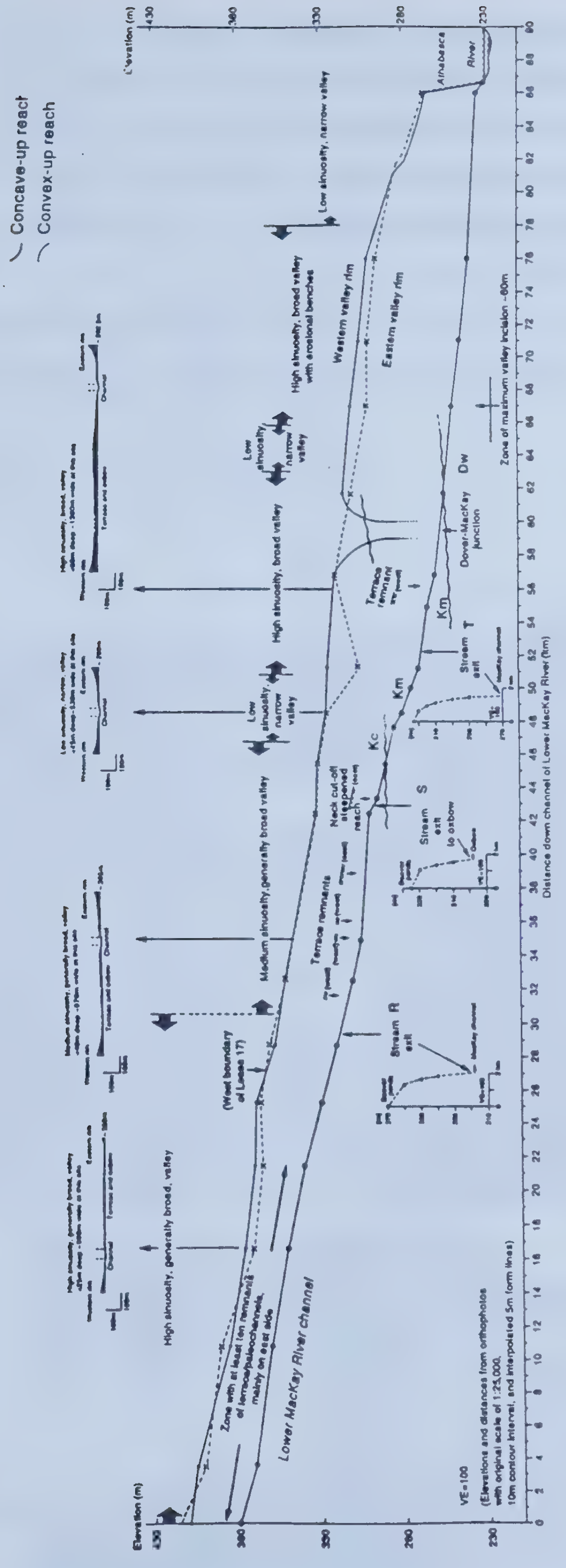
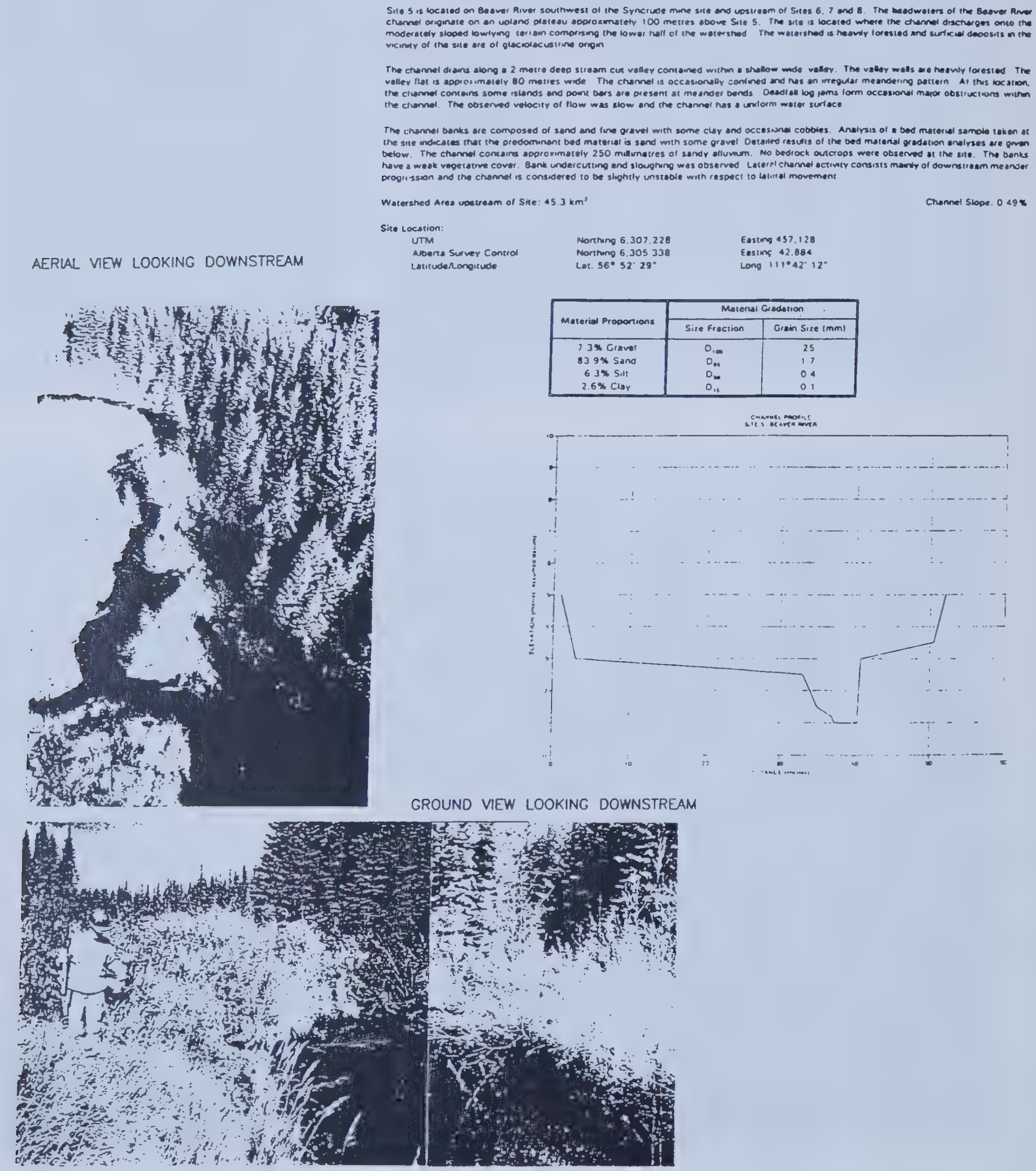


Figure 4 - Longitudinal profile of the MacKay River

A second study was initiated to document typical streams and rivers in the vicinity of the Syncrude site. This study included investigation of 40 different sites, some of which were located on different reaches of the same river or stream. Bedding material, typical cross-sections bedding slopes and meandering patterns where recorded and documented[10] (Figure 5). This information will be used to help in the re-establishment of areas to pre-disturbance conditions.



Site 5 is located on Beaver River southwest of the Syncrude mine site and upstream of Sites 6, 7 and 8. The headwaters of the Beaver River channel originate on an upland plateau approximately 100 metres above Site 5. The site is located where the channel discharges onto the moderately sloped lowlying terrain comprising the lower half of the watershed The watershed is heavily forested and surficial deposits in the vicinity of the site are of glaciolacustrine origin

The channel drains along a 2 metre deep stream cut valley contained within a shallow wide valley. The valley walls are heavily forested The valley flat is approximately 80 metres wide The channel is occasionally confined and has an irregular meandering pattern At this location, the channel contains some islands and point bars are present at meander bends Deadfall log jams form occasional major obstructions within the channel. The observed velocity of flow was slow and the channel has a uniform water surface

The channel banks are composed of sand and fine gravel with some clay and occasional cobbles. Analysis of a bed material sample taken at the site indicates that the predominant bed material is sand with some gravel Detailed results of the bed material gradation analyses are given below. The channel contains approximately 250 millimetres of sandy alluvium. No bedrock outcrops were observed at the site. The banks have a weak vegetative cover. Bank undercutting and sloughing was observed Lateral channel activity consists mainly of downstream meander progression and the channel is considered to be slightly unstable with respect to lateral movement

Watershed Area upstream of Site: 45.3 km^2

Channel Slope. 0 49%

Site Location:

UTM	Northing 6.307.228	Easting 457,128
Alberta Survey Control	Northing 6.305 338	Easting 42.884
Latitude/Longitude	Lat. 56° 52' 29"	Long 111°42' 12"

AERIAL VIEW LOOKING DOWNSTREAM

Material Proportions	Material Gradation	
	Size Fraction	Grain Size (mm)
7 3% Gravel	D_{100}	25
83 9% Sand	D_{85}	1 7
6 3% Silt	D_{50}	0 4
2.6% Clay	D_{15}	0 1

GROUND VIEW LOOKING DOWNSTREAM

Figure 5 - Stream investigation summary sheet

The performance of reclaimed surfaces will affect the performance of the man-made streams. Relationships between pre-disturbance streams and reclaimed, man-made ones will be influenced by the difference in the characteristics of the basins they drain. Syncrude is monitoring runoff of some reclaimed surfaces and smaller undisturbed catchments by measuring streamflow (Figure 6). Syncrude plans to continue this activity for many years in order to collect a representative database. Syncrude also plans to test reclaimed streams made predominantly of clay and rock (know locally as bouldery ground) by monitoring erosion in response to a range of representative streamflows. This will establish relationships between natural and reclaimed streams and rivers.

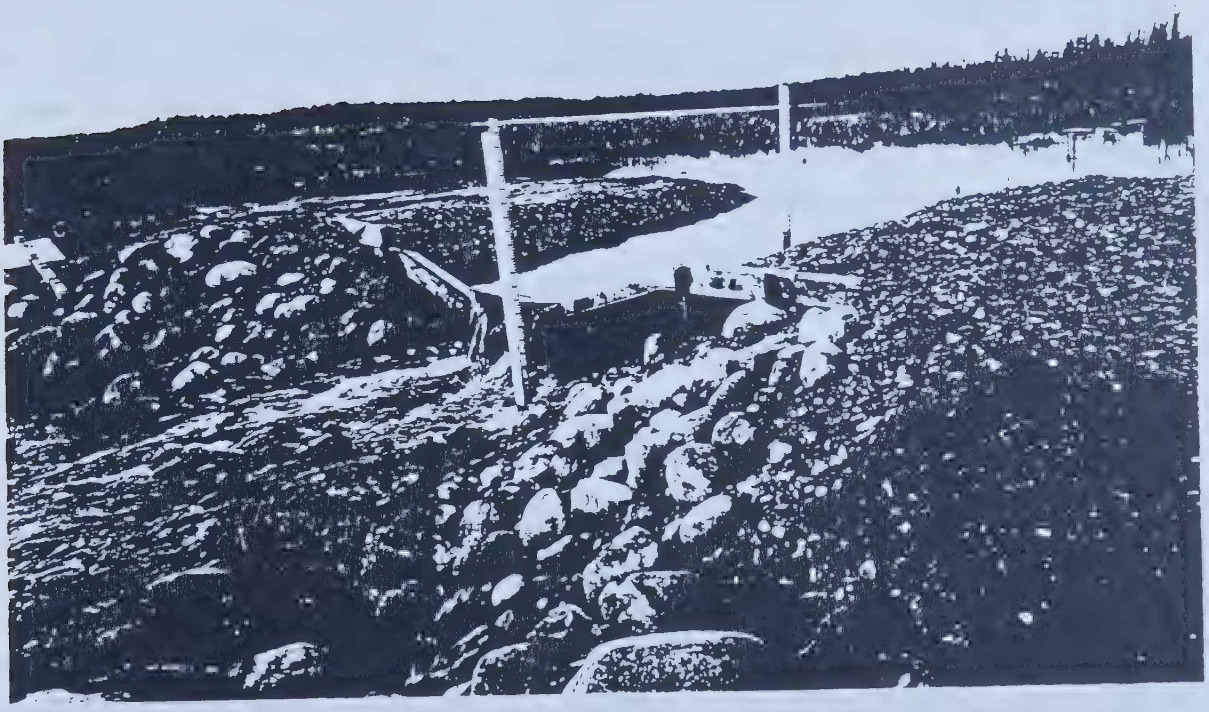


Figure 6 - Streamflow monitoring station at Syncrude

The activities that involve undisturbed surfaces, such as documentation of natural streams and rivers and monitoring of runoff by measuring streamflow, should ideally precede development. This has occurred to a limited extent at the existing developed leases but is being implemented fully on the new Oil Sands leases. Climatic stations have also been installed on existing and new leases. Monitoring includes precipitation, evaporation and snowfall in order to accurately measure localized precipitation events that would affect runoff and streamflow within regional watersheds.

Lake Design

Syncrude currently plans to construct two deep water-capped lakes and several shallow wetlands as part of the lease closure landscape (Figure 7). One of these deep lakes, intended as a demonstration lake, is currently being built and is scheduled to be fully operational by 2010.

Lakes are complex features involving beaches, littoral zones, thermo- and chemoclines, wave action, detrital layers, and islands. Although Syncrude's deep lakes will be different than regional lakes, some common features will exist. Examination of the biological aspects of regional lakes has been conducted and most recently the examination of topographic maps and aerial photographs, as well as flyovers of 29 lakes (with landings on 7) in the area have yielded valuable information about shoreline stability that could influence the design of the demonstration lake.

The development of littoral zones influences biological productivity, habitat and erosion control. Many lakes observed in Northeastern Alberta are less than 2 m deep, densely vegetated (100% littoral), and show little shoreline erosion. The wave forces are insufficient to dislodge the vegetation. The deeper lakes have a different mechanism of erosion protection. They have gravel and cobble shores and show capability of self armoring by exposure of the gravel, cobbles and boulders in the lakeshore soils (Figure 8).

Shoreline stability could be threatened by ice. Preliminary observations show that on the shallow lakes, the emerging vegetation is sometimes torn from the shoreline and pushed up on to the bank to create ice berms. This may become an issue, especially if breakwater islands are employed. Ice effects is an area not yet fully investigated.

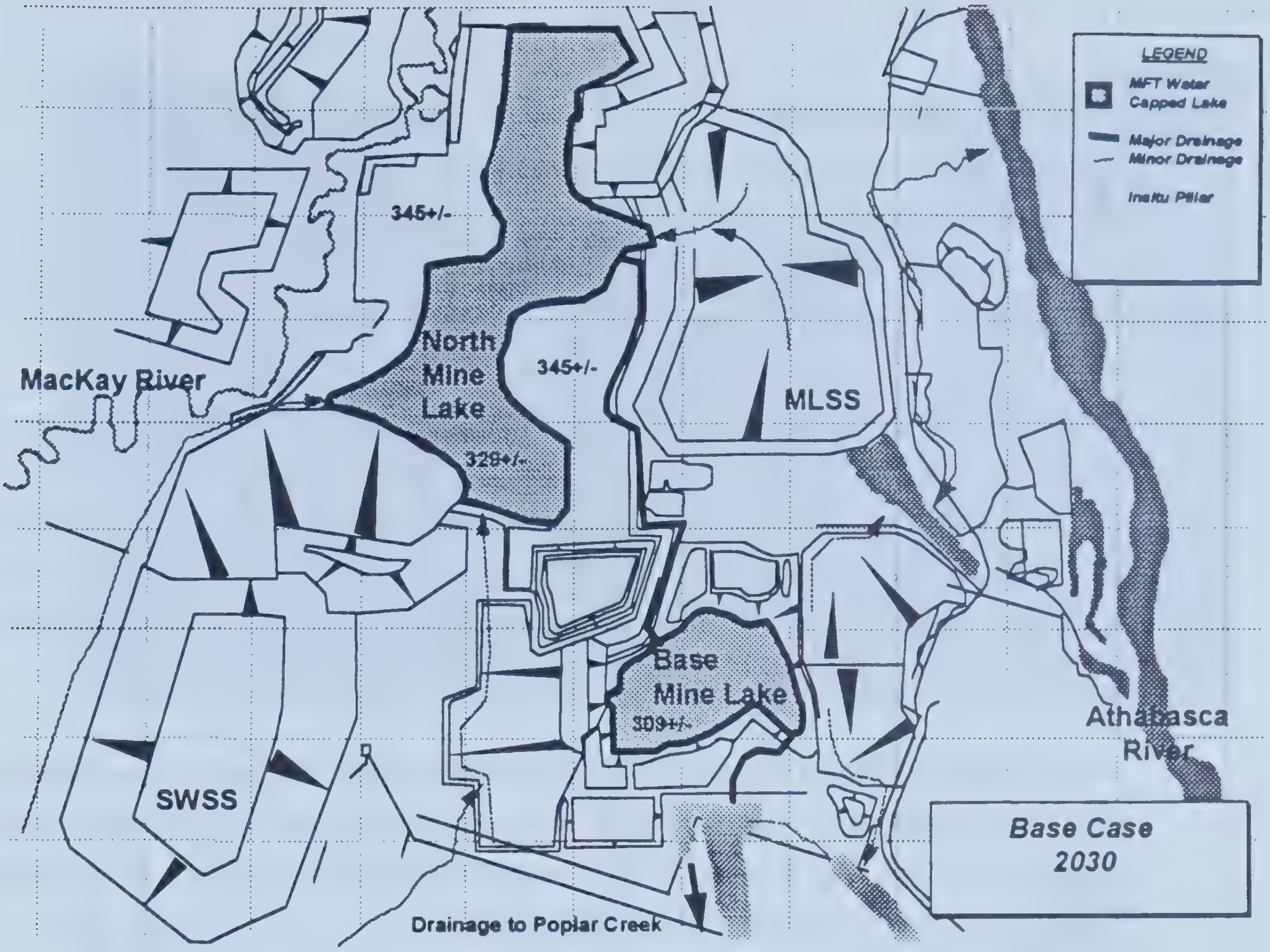

LEGEND
MFT Water Capped Lake
Major Drainage
Minor Drainage
Insitu Pillar
345+/-
North Mine Lake
345+/-
MacKay River
329+/-
MLSS
Base Mine Lake
309+/-
Athabasca River
SWSS
Base Case 2030
Drainage to Poplar Creek

Figure 7 - A final drainage plan

Figure 8 - Shoreline protection of a deep lake near Syncrude

Beaver Dams

It is unrealistic to expect that all surface water flows will be fully contained. Beaver dams have the capability to divert streams to adjacent watersheds. This was documented at three locations along the MacKay river where beaver dams caused landslides due to increased elevation of water tables (Figure 9).

Most other erosion mechanisms are somewhat quantifiable but the beaver dam concentration will vary with a multitude of factors including available food source and population of beavers. Dams on creeks are common at the Syncrude leases. Approximately, 1000 beaver dams presently exist at the leases and will continue to do so after closure. Therefore Syncrude retained Alberta Environmental Center to help examine natural impacts from beaver dams on lakes, rivers and streams.

It was found that beaver dams have the potential to raise water levels by damming the outlets of lakes a short distance downstream of the outlet. Despite the fact that the forest cover and soils at the outlets of most natural lakes are not conducive to beaver dams, four of 29 large lakes within 80 km of Syncrude, are controlled by beaver dams.

Steep chute channels will be part of the lease-closure landscape and therefore beaver dams in gullies were also investigated. Beaver dams were found to reach heights of 3m (Figure 10) and where cascading failures occurred, there was evidence of bank erosion.

Nevertheless, the net influence of beaver dams is a significant reduction in erosion by trapping sediment and attenuating flows. On the basis of these preliminary results, lease-closure streams and lakes will be designed to accommodate beaver dams[11].

Figure 9 - Landslide along the MacKay River caused by beaver dams

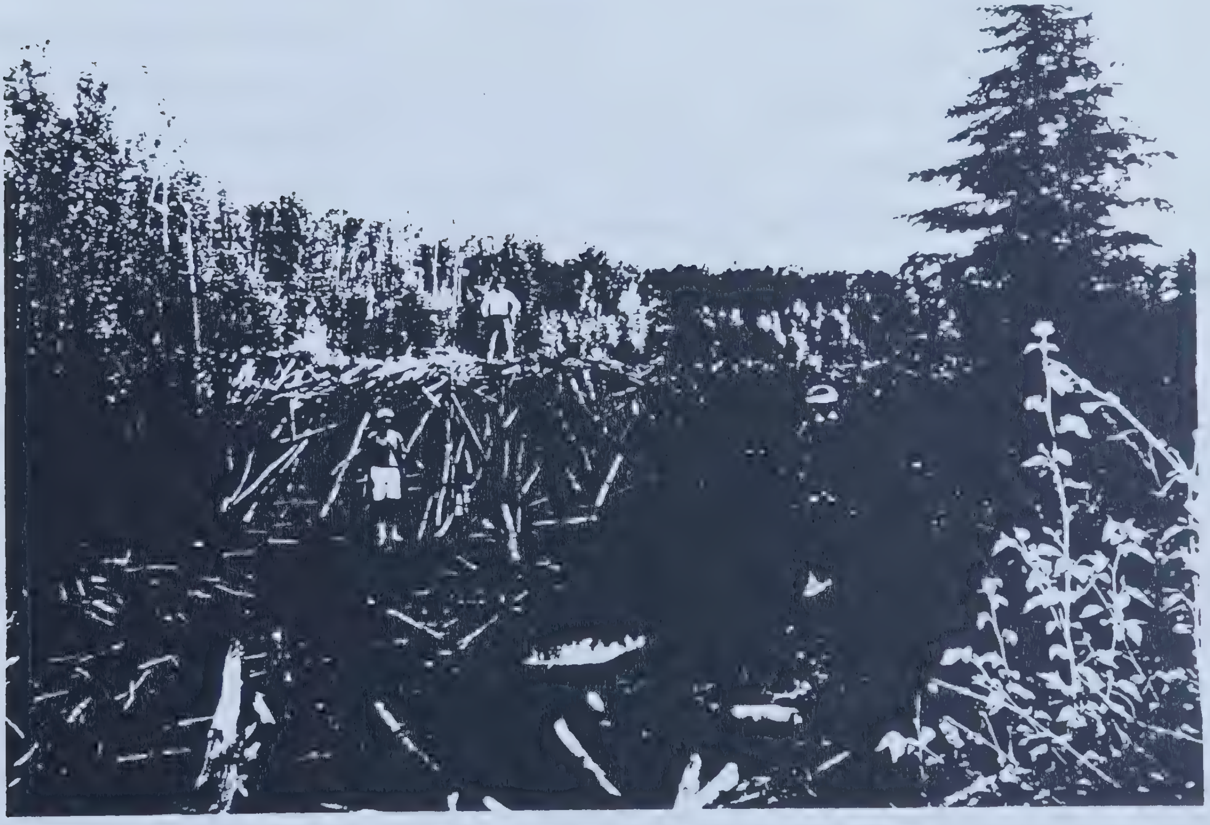


Figure 10 - Series of 3 m high beaver dams around Ft-McMurray

Geotechnical stability

Fluvial geomorphology of creeks, streams and rivers was highlighted as the most important natural analog, as is precipitates erosion. However, the effect of erosion on geotechnical stability is also a significant concern. As mentioned earlier, a geotechnical risk assessment was performed on various landscape alternatives representative of different tailings disposal techniques. Certain "safety mechanisms" were recommended based on existing knowledge of gullying and bank failures. However investigation of related natural analogs is ongoing and will help validate and assess potential existing and future erosion development.

Erosion may be manifested as gullies, and as such, represents a failure mechanism potentially causing breaching of water and tailings filled lakes. Gullies in natural areas are the focus of an ongoing study to map their geological and fluvial nature and measure their rates of erosion. These will be compared with gullies forming on existing reclaimed areas.

Landslides are another form of instability observed frequently in Northeastern Alberta. In the Syncrude lease areas, approximately 100 active landslides were observed and documented on the MacKay River. Other major river valley slopes show evidence of past occurrences of landslides as well. The processes of landsliding and gullying are a natural part of the erosion process. They should be acceptable in the reclaimed landscape so long as breaching of tailings containment is avoided. Consequently, offsets from the MacKay River will be revised to provide more in-situ material between the river and any tailings containment (Figure 11). Barrier fills of 500 m to 1000 m wide with sufficient freeboard to permit settlements and erosion will be employed to insure geotechnical stability of water and tailings containment. A vegetated and armored low point in the lake barrier fills would serve to reduce all risk of lake overtopping, and would allow for a controlled relocation of the drainage path. This "emergency spillway" would reduce the risk of a catastrophic breach. Further, existing gullies could be strengthened using riprap and bouldery ground to slow initiation and development of future gullies.

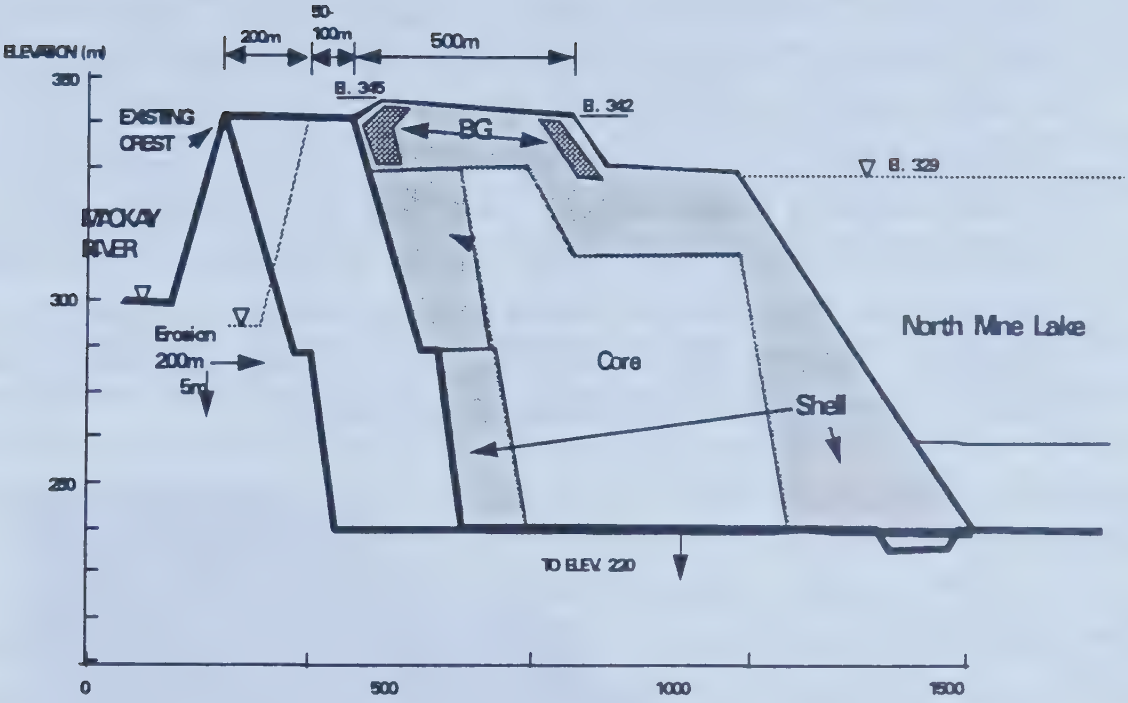

ELEVATION (m)
350
300
250
200m
50-
100m
500m
EL. 345
EL. 342
EXISTING
CREST
BG
EL. 329
MACKAY
RIVER
Erosion
200m
5m
North Mine Lake
Core
Shell
TO ELEV. 220
0
500
1000
1500

Figure 11 - Cross-section through the North Mine showing revised offset from the MacKay River

Bouldery ground has been mentioned for use in establishing the robustness of streams and rivers, lake shoreline and gullies. A robust landscape design is one which is inherently stable despite inevitable evolution over geological time frames. Tailings which consolidate and increase in strength with time are robust. Overburden dumps which have decreasing pore-water pressures are also robust. Finally streams, lake shoreline and gullies that contain this bouldery ground within the bank and bed materials will self-armor and become more stable as erosion occurs. The main components of bouldery ground would be clay and rock. Studies have commenced on the rock types that could be used. The tills are mostly composed of weathered Oil Sand and shale and are characteristically fine grained and have low rock content. Deposits of gravel are relatively rare and already exploited for operation. There are however, within the Oil Sand and more importantly in the Clearwater Formation overburden, numerous siltstone layers which may be used as the rock component of the bouldery ground. Freeze-thaw weathering of these siltstones is under investigation.

Aeolian erosion

Over 50 km² of landscape will include tailing sand structures. They will rise to 60 m over the natural, undisturbed topography making them susceptible to wind and water erosion. These areas are being capped with soil and planted. There is a concern for aeolian erosion creating gullies in the tailings sand and that further windblown deposits may affect vegetation in other areas leading to more-widespread aeolian erosion. Areas east of the Athabasca River consist of stable vegetated dunes and sandsheets (Figure 12) with the exception of two areas to the northeast which have active dunes. Studies of these areas are underway, particularly to investigate the role of emergent vegetation and it's stabilizing effects on sand structures. There is evidence of vegetation stabilizing gullies and lessening further erosion

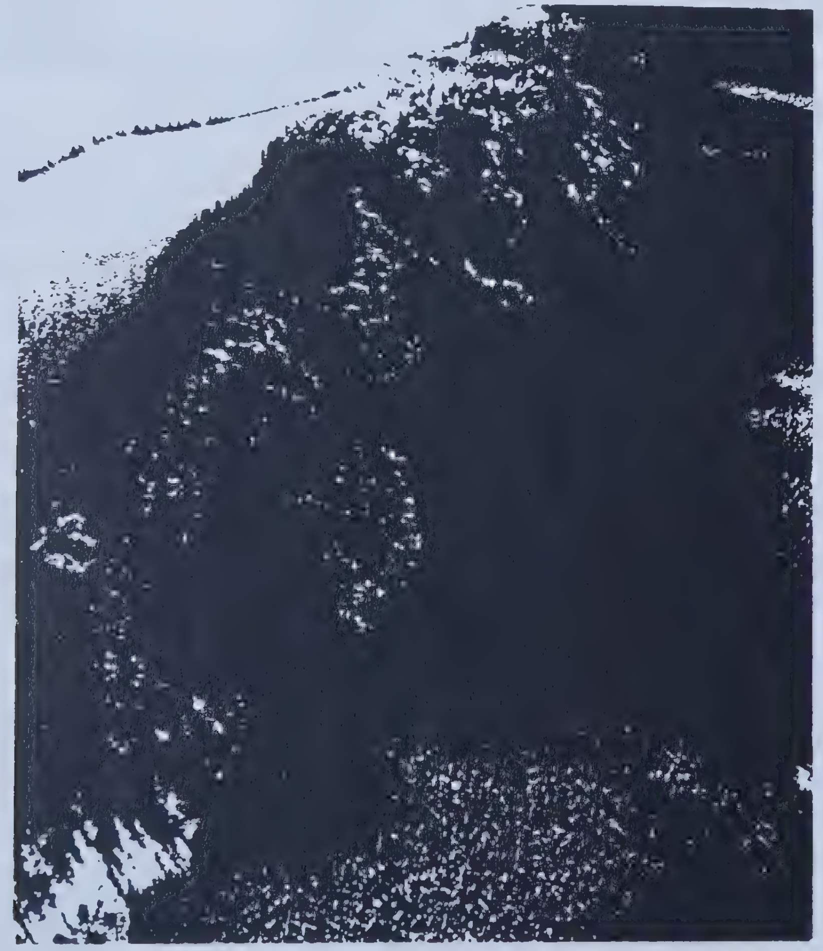


Figure 12 - Vegetated Sand Dunes

Post-closure monitoring

Syncrude recognizes that the reclaimed landscape will be subjected to unrestricted access for road building, logging, hunting, fishing, recreation and future development. A maintenance agreement with the government or third parties would be subject to changes in these organizations as most governments and other organizations historically have short lifespans. Therefore, apart from a planned post-closure monitoring period, on-going maintenance is not part of the Syncrude design. If however, maintenance was to become an option, even over a fixed period, small fix-ups and changes at key times could minimize the effects of erosion and geotechnical instability.

One might not expect all aspects of the reclaimed landscape to accomplish the design objectives upon commissioning. Therefore two timely elements are in place. First, as mining continues, areas are reclaimed and monitored providing an opportunity to study the effects of nature on the landscape and to allow for repairs during operation. Second, the post-closure monitoring period will allow minor changes to the landscape based on years or decades of further monitoring prior to final signoff. By lease-closure, in approximately 2035, Syncrude will have 50 years of performance data for some reclaimed areas. This data would include, for example, tree growth, erosion, release-water quality and streamflow. Syncrude is presently developing, with regulatory consultation, lease sign-off criteria for this post-closure monitoring period.

Economics

Ultimately, any design must take into account economics of the resource development including capital and operating costs, cash flow, and material availability. If the design of the reclamation landscape were left until the declining years of a project, the costs would be excessive and the final landscape sub-optimal.

Findings to date suggest that the improvements required to assure long-term stability are often a question of working smarter versus working harder. This could be accomplished by diverting specified overburden, necessary for long-term landscape development, to certain locations for little additional cost over transport to waste piles. In addition, there may be enhanced mining or tailings practices which could provide better reclamation designs. For example, in-situ pillars could be left to reduce the risk of a lake breach, slopes could be designed at an angle that is attractive for reclamation, and out-of-pit dumps could be strategically located for optimal lease drainage patterns. Natural analogs would be one of many necessary tools to influence design. There are inherent trade-offs — how should money and effort be divided between various reclamation activities? From a societal perspective, how much effort should be put into reclamation, and how should it be balanced to protect against short-term versus long-term risks? The hazard assessment identified difficulties involved in assessing low probability with high consequence events (such as a breach of a tailing or water retaining structure) or low annual probability extended over millenniums. It is difficult to evaluate the acceptability of catastrophic events even in the far future. It was therefore found that the best concept in evaluating various development plans is to list the economic issues from inception to closure and the qualitative ratings of the hazards associated with each plan.

Summary

Designing for closure is now mandatory in all jurisdictions in Canada. Conventional criteria for reclamation are less appropriate for large reclaimed landscapes which need to be designed to be self-sustaining for hundreds to thousands of years. Instead, the design philosophy of building a robust and mature landscape based on natural analogs is a more reasoned approach.

The design of the mining and tailings systems must be conducted in close collaboration with reclamation planning to minimize short and long term risks while remaining economically attractive. The reclamation plan must be dynamic so that it can adapt to new information available from the natural environment, experience at reclaimed areas, changes in mine plans, introduction of new technologies and acceptance by stakeholders and regulators. It is important, throughout these processes to maintain careful documentation, open information sharing and involvement of various specialists, stakeholders and regulators in the decision making processes.

Investigations into natural analogs, including streams, rivers, lakes, hillslopes, dunes and landslides is continuing on all Syncrude leases. The information gained from these investigations will be critical in the ongoing development and optimization of the Syncrude lease-closure plan.

Acknowledgments

The work presented here is the result of many people in various disciplines, both internal and external to Syncrude. External expertise was provided by Dr. R.B. Rains, Dr. S. Schumm, Dr. E. McRoberts, Mr. R. Dawson, Ms. M. Caine, Mr. L. Roy. Syncrude is thanked for its support and for permission to publish this work.

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REHABILITATION AT HBM&S MINES NORTHERN MANITOBA, CANADA

FOR PRESENTATION AT

ENVIRONMENTAL MANAGEMENT FOR MINING
SASKATOON, SASKATCHEWAN
OCTOBER, 1995

Wayne Fraser
Stephen West
Hudson Bay Mining & Smelting Co., Limited
P.O. Box 1500
Flin Flon, Manitoba, Canada, R8A 1N9

Phone: 204-687-2171
Fax: 204-687-5793

REHABILITATION AT HBM&S MINES
NORTHERN MANITOBA, CANADA

Synopsis

Hudson Bay Mining and Smelting Co., Limited, a Canadian company, has operated a copper smelter and zinc refinery at Flin Flon, Manitoba for nearly 65 years. During that time, 28 mines have provided feed to eight concentrators. Five mines are currently operating, as are three concentrators.

Over the last decade, the environmental liability of the shut down operations has been recognized, and HBM&S has embarked on an aggressive - and expensive - decommissioning program. Two mills and ten mine sites have been completed; work is currently underway on five mine sites.

During decommissioning, one point continues to emerge - had mine and mill planning, construction and operation been done differently, very large sums of money could have been saved at the time of closeout. Every mine must close sooner or later - designing should be done with closure in mind.

Hudson Bay Mining and Smelting Company, Ltd., a Canadian Company, has operated a copper smelter and zinc refinery at Flin Flon, Manitoba, for nearly 65 years. During that time, 28 mines have provided feed to eight concentrators. Four of the mines were combined open pit and underground, with the remainder solely underground. Mines have ranged in size from less than 100 000 to nearly 60 million tonnes. At the moment, five mines are being operated - one recently opened; three concentrators are running while one is on standby.

In the early days, two mill sites and seven mine sites were dismantled or turned over to others. Over the last decade the remainder have become environmental liabilities requiring decommissioning. Two mill and ten mine sites have been completed; work is currently underway on five mine sites. Some six million dollars Canadian has been spent or committed to date for these projects; many more millions will be required for the remaining sites.

During decommissioning, one point continues to emerge - had mine and mill planning, construction and operating been done differently, very large sums of money could be saved at the time of closeout. Every mine must close sooner or later - designing should be done with closure in mind.

The concept of designing for closure is, in principle, simple - look into the future to the end result and the waste products that will be left behind, and design the most economical management and operating plans which will cause the least harm to the environment. These plans, when conceived, should consider the proposed project and its operations, and design them to meet satisfactory closure and decommissioning criteria.

Over the history of mining, our industry has traditionally disposed of waste products into the environment in the most economical manner. The general attitude was to concentrate efforts on the extraction of the mineral and pay little attention, if any, to the nature of the waste products, their long term stability, and the impacts that they could have on the environment. Today, the consequences of such waste management practices are well documented.

Engineering principles have been evolving that address the long term stability of waste products. We can now examine both the chemical and physical stability of waste materials. We have two choices - plan ahead and handle things properly the first time, or do things as we used to and do the clean up later, at markedly higher cost.

When I speak of waste materials and waste products, I am speaking of everything left at the end of a mine life that is different than, or in a different place than it was before the minesite was developed. That basically includes everything after re-usable equipment is removed.

When a minesite is decommissioned:

- The operator should be protected from all foreseeable future environmental liability.
- The regulators, and perhaps more importantly the public, must be satisfied with the end product.

The latter point may include a large measure of aesthetics, and may or may not be based on prescriptive regulations or guidelines. In any case, foresight should be combined with a good measure of doing more than is required, to simply meet existing regulations.

The following comments on maxims that appear to have guided mine design in the past reflect experiences of operations in the forested regions of Canada, but it is hoped that they provide insight applicable to mining areas anywhere in the world.

Minesites and Access

> "You never know what you may need in the future, so make the site big." "The shortest distance is a straight line, so let's make the roads and service corridors straight."

Sound familiar? But why not make the site as small as you can, and perhaps leave a few clumps of native vegetation behind. Access roads, power and pipeline routes, should be curved to prevent a direct line-of-sight from public areas to the mine. When site preparation is being done, overburden and soil should be cleared and saved for eventual decommissioning.

Buildings

> "Let's over design - nobody will ever know, and we do not want these to fall down."

Mines, unfortunately, are not forever. So why do we lay concrete and build structures to last forever? It is difficult to defend leaving concrete foundations and footings behind - we mine millions of tons of rock but can't remove a few hundred tonnes of concrete? We also tend to put enough reinforcing bar in our concrete to make a lot of steel mills very happy. Why not design concrete with structurally-acceptable break points, and why not cast in-place plastic tubing which can later be packed with explosives to break up the concrete for removal.

As to the buildings themselves, most of the smaller buildings can be reused or sold if dismantling costs are reasonable. If dismantling is considered when buildings are designed and specified, this reuse can be made easier. Materials of construction, insulation, etc., must be carefully considered. Other buildings - and particularly metal headframes - may not be economically reusable. They can, however, be converted to scrap at a reasonable expense if appropriate dismantling techniques and equipment are employed.

Wastes and Spills

> "Bury it - nobody will ever know."

Some of the biggest surprises in dismantling minesites is the amount of foreign material that has been buried. Some sites have as much scrap buried on them as is yielded by the dismantling of the buildings. There is nothing fundamentally wrong with properly managed landfill operations. However, wastes must be segregated - metals, combustibles, domestic - and utmost attention must be paid to ensuring that no chemicals or hazardous wastes get disposed with non-hazardous materials. Further, petroleum products and soluble or liquid process chemicals must be stored in impoundment areas with impervious liners to protect ground water and to stop contamination of otherwise clean site material.

Waste Rock

> "We produce two things - ore and waste rock. And waste rock makes good construction material."

The biggest cost we have in decommissioning minesites is in dealing with acid generating mine rock. HBM&S mines are all sulfide based and, except for one, have acid rock problems. Without recognizing the long term liability of this rock, we have used it both on and offsite for civil works. Current and future mining will consider that we produce three materials - ore, stable rock, and acid-generating rock.

There are literally dozens of types of tests which can be used to determine the acid generating potential of rock, the dynamics of the reactions, and so forth. Some are technically elegant, others are quite expensive. But in the end, one should not rest comfortably on the selective choice of methods to prove that a rock is not going to be a problem at some time in the future.

The simplest test is that of determining the amount of sulfur present, presuming that all of it will become acid, and comparing that to the titrated value for acid consuming ability. After that, we need to make a judgement call - will or will not the material in fact be a net acid generator?

To decompose to acid, three things are necessary - sulfur, air, and moisture. If either of the last two can be controlled, acid generation will not be a problem, whatever the sulfur level. Arid climates provide little moisture, or in any case, perhaps no vehicle to transport generated acid out of a rock pile, and there may be no problem. In other climates, control can become a significant problem or at least a significant cost.

In Canada, under a joint industry-government research program called MEND - Mine Environment Neutral Drainage - some $18 million (Canadian) has been or will be spent researching ways and means of achieving control of acid generating materials. The best method has been determined to be placing fresh material underwater. Second choice, and a distant second, is covering the material with an engineered, multi-layered, soil cover. Better than both of these is leaving the suspect rock where it was - in the mine - or placing it there post-operation.

Which brings us to the planning phase. When we do exploration drilling to define an ore body, we are in the position to determine a great deal about the host rock through which we will be driving declines, sinking shafts, and doing development work or that we will be stripping for open pit mining. By doing the afore-mentioned acid/base accounting on the rock, we can determine, before mining, whether the rock will present a problem. After we have removed the rock, and mixed it together in a pile of several hundred thousand tonnes, we have a major problem - all the rock is contaminated if any of it is, and how can we representatively sample the pile in any case?

So how do we know, or how can we predict with surety whether a material will be acid generating? If the acid potential exceeds the neutralizing ability, there is no question - net acid will result. Beyond that, the mechanism of the reactions must be understood, and the composition of the rock must be viewed within that context.

When sulfur-containing minerals decompose to form sulfates, continuous renewal occurs of fresh mineral faces for subsequent reactions. Sooner or later, essentially all the sulfur will be converted, with the rate of reaction being the only unknown. Neutralizing minerals, on the other hand, tend to get occluded with precipitation salts, and may only be partly consumed before they are rendered inert. Complicating the situation are physical factors such as the degree of homogeneity in the rock - stringers versus intimately mixed microscopic crystals - and the relative size of the rock. Various rules of thumb are available to assist in interpreting the acid/base data:

- minimum 20 kg per tonne of excess alkalinity required.
- ratio of base to acid of at least two to one, and in some cases as high as four to one required.

With a fine grain, well mixed, crushed rock of low sulfur content, less than 0,5%, the low side of these rules of thumb are probably reasonable. With higher sulfur, or irregular rock, the higher side would ensure safe prediction. The ultimate test is in the field, of course, but it may take years for an acid "breakout" to occur, at which time red coloration and elevated sulfate seepage becomes evident.

With a prediction of the probable stability of particular rock units while they are still in the ground, a decision can be made as to whether the rock can be safely used for civil works - roads, site levelling - or whether it should be stockpiled for later rehandling, mitigated in the short term such as with a water cover, or left in the mine or returned to the mine as backfill. The additional money spent during design, development and operations for a proper waste rock program can mean economic returns many times greater at time of closeout.

Handling of rock which is already oxidized presents different problems than that of controlling oxidation in fresh rock. Underwater disposal of oxidized material will lead to release of soluble values and contamination of the overlaying waters. Once placed underwater, no additional sulfide decomposition will occur; control and mitigation may well require water treatment for a period of time, but at least the time will be finite.

Some Concepts Used Successfully

- Contaminated water management at a site can result in two streams to be handled - mine dewatering effluent and runoff. If the precipitation regime allows it, contouring and sloping of the site to direct surface drainage from ore and mine rock piles into the underground collection sump system results in a single waste stream and pumping system.
- Head frames can be particularly expensive to dismantle, and yield little reusable structural steel. Recognizing the strength built into these structures, we have developed a simple means of dismantling which does not require the use of cranes. The structures are burned, followed by cutting one metre long sections out of all but four of the vertical members. These are then blasted to topple the structure. A hydraulic shear on a back-hoe boom is then used to cut the steel into short, recyclable lengths.

- Shafts, raises, and underground stopes provide secure storage of acid-generating and pre-oxidized rock. At the end of mine life, a raise driven to surface from an open stope can provide access for dumping; an engineered concrete plug set in bedrock isolates the rock and it's products from the surface environment.

- Most open pits will eventually become lakes; problem rock can be layered in the bottom of a pit and covered with silt or clay. The pit water can be treated or otherwise managed during initial flooding and to remove contaminants leaching from the rock.

- In-situ treating of water while waste is being placed in a pit offsets the need for separate treatment. Broadcasting of slurried lime on the water surface, followed by a short period of settling, allows the treatment sludges to settle into the voids in the rock mass. Clean water is then decanted; an impervious clay cover when the pit is filled then seals the sludge and rock in place and prevents re-mobilization of contaminants.

- As a final step in decommissioning, the site should be fertilized but seeding may not be necessary or even desirable. Establishing a non-natural vegetation mono-culture may well hinder site recovery, while a site merely fertilized will begin natural growth succession. If erosion is a problem, a non-reseeding annual plant will provide sufficient surface stabilization to allow "mother nature" to seed the site.

- At least a portion of the decommissioning work can be done while the mine is still operating. The availability of manpower and equipment, as compared to the high cost of mobilizing after operations are shutdown, make it desirable to do all that is possible while the mine is still running.

Mine closures are an unfortunate but predictable step in our industry. Properly planned, they can be done at an acceptable cost. The time to start that planning is before mining even begins - planning for closure makes sense.

Acknowledgements

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HYDROGEOLOGICAL CHARACTERIZATION OF A WASTE ROCK PILE

G. M. Herasymuik[1], G.W. Wilson[2], S.L. Barbour[2], T. Smith[3]

[1] Graduate Student, Department of Civil Engineering
University of Saskatchewan
Saskatoon, Canada, S7N 0W0

[2] Professor, Department of Civil Engineering
University of Saskatchewan
Saskatoon, Canada, S7N 0W0

[3] Reclamation Scientist
Golden Sunlight Mines Inc.
Whitehall, Montana

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[3] Reclamation Scientist
Golden Sunlight Mines Inc.
Whitehall, Montana

ABSTRACT

The flow of water and the movement of oxidation products in large sulfide bearing waste rock piles has received limited attention. The ability to predict the physical processes that deliver contaminated seepage from unsaturated heterogeneous waste rock piles, to the environment, requires a better understanding of the physical and hydrogeologic characteristics of the waste rock pile.

The Department of Civil Engineering at the University of Saskatchewan has initiated a multiphase research program to define the distribution of water and the pathways for water flow in a large unsaturated waste rock pile. Partial excavation of a waste rock pile provided a unique opportunity to study the internal structure and processes active in the pile. The first phase of the research program consisted of a field logging and sampling program conducted simultaneously with the excavation operations. The second phase of the research program was a laboratory program for the evaluation of the hydrogeologic characteristics of the samples obtained during the first phase of the research program. This included the measurement of grainsize distributions, soil water characteristic curves for water content versus suction, and saturated hydraulic conductivities for the evaluation of the relationships for unsaturated hydraulic conductivity versus suction.

The results from the field and laboratory program will provide the basis for future research at the University of Saskatchewan. This research will focus on the surface water balance, heat and mass transport processes, liquid water retention characteristics, drainage, vapour diffusion and the potential for seepage at the base of the pile. This paper briefly summarizes some of the results from the field and laboratory program.

INTRODUCTION

Acid rock drainage (ARD) from sulfide bearing waste rock is a significant environmental concern for the mining industry in Canada. Reclamation costs related to the containment of acid drainage from sulfide bearing waste rock piles and tailings is expected to approach 3 billion dollars over the next twenty years (Filion and Ferguson, 1990). Acid is generated as a product of the oxidation of sulfide minerals when exposed to the atmosphere. The prediction of ARD from waste rock piles is required for the development of adequate reclamation and decommissioning plans.

At present, the understanding of solute transport in unsaturated heterogeneous waste rock piles is limited. Waste rock piles are typically heterogeneous as a result of the variability of the materials dumped in the pile and the methods of construction. Characterizing the hydrostratigraphy of waste rock piles and the hydrogeologic properties of the individual materials is needed to define the pathways for unsaturated water movement and solute transport. The hydrogeologic processes active in the dump will affect the quality and volume of water that may enter the environment. An understanding of water flow in an unsaturated heterogeneous waste rock pile will lead to improved predictive modelling capabilities.

BACKGROUND

The University of Saskatchewan conducted a research program for a large waste rock pile at the Golden Sunlight Mine located in S.W. Montana. The removal of approximately 15 million tons of waste rock from a 100 million ton waste rock pile provided the opportunity to obtain samples and document the internal structure in the pile. The excavation provided access to material ranging from recently deposited material to waste rock subjected to oxidation in the pile for more than ten years.

Shale and latite porphyry rocks comprise the majority of the rock types in the waste rock pile. Massive and disseminated sulfide mineralization is found in both rock types (Foster, 1991). Unoxidized waste rock at the mine site generally contains 2 to 5% pyritic S and has no significant neutralizing capacity (Schafer et al., 1994).

RESEARCH PROGRAM

A multiphase research program was initiated to define the internal stratigraphy and characterize the physical and hydrogeologic properties of the waste rock material found within the waste rock pile.

The specific objectives of the research program were:

1. to observe and sample the waste rock material and obtain insitu measurements,
2. to define the distribution of water within the waste rock pile,
3. to classify the waste rock material on the basis of physical characteristics,
4. to define the hydrogeologic characteristics of materials previously classified,
5. to identify potential pathways for liquid water, water vapour and oxygen flow, and
6. to provide a conceptual model of the heat and mass transport processes based on the physical and hydrogeologic properties of the waste rock and the internal stratigraphy of the waste rock pile.

The first phase of the program involved a field logging and sampling program conducted during the excavation of the waste rock pile. The second phase consisted of a laboratory program that focused on the physical and hydrogeologic properties of the waste rock material.

The field program was conducted simultaneously with the excavation operations. The excavation operations involved removing the waste rock in approximately 18 m benches. Transect lines were established on the bench surfaces created during the excavation operations along which test pits were excavated. The transect lines were orientated to access the greatest range of years during which the material was placed in the waste rock pile. Test pits were excavated at spacings between 30 and 90m depending on accessibility and generally ranged from 3.0 m to 4.6 m in depth. The transect lines were re-established and test pits were again excavated on the subsequent lower levels as each bench was excavated. In this way, data was obtained at various depths and locations within the pile as the waste rock was removed. In this manner, a data base was established that represents approximately a 100m deep cross-section through the waste rock pile.

A standard logging and sampling procedure was used for each test pit. The waste rock pile was found to contain a well defined structure characterized by changes in grainsize distribution and/or colour. All layers encountered within a test pit were visually logged with respect to waste rock type (i.e. intrusive varieties vs. shale varieties), grainsize range, texture, structure, condition of interparticle spaces (i.e. either open voids or interparticle spaces infilled with fine matrix), state of oxidation and weathering, colour (i.e. Munsell soil colours), strike, dip and any other special features that were observed (Herasymuik et al., 1995). All layers were photographed.

Insitu measurements of matric suction, temperature, relative humidity and gravimetric moisture content were obtained. Tensiometers and the filter paper method were used to obtain insitu measurements of matric suction. The tensiometer measurements were found to only be suitable in fine grained layers with higher water contents. Many layers were very dry (water contents of less than 1%) and suctions values in these layers exceed 90kPa. Tensiometers are only useful for suction measurements below 90kPa due to the cavitation of water in the tensiometer. The filter paper method was also used to attempt to obtain insitu total and matric suction values. Temperature and relative humidity measurements were taken using a portable temperature and relative humidity sensor. Moisture contents were obtained for each layer sampled except for those which were too coarse to sample. Moisture contents were obtained for both the bulk material and material smaller than 9.5 mm for each layer sampled.

All test pits were surveyed and tied into the mine grid. The coordinates and elevations allow the position of the test pit to be determined with respect to their depth below the original surface of the pile and elevation relative to the original ground topography (i.e., the base of the pile). As-built drawings and survey data were used to determine the year that the materials in each test pit were placed in the pile. This data allows comparisons to be made between the physical and hydrogeologic properties and the associated locations and ages of the various materials.

The focus of the laboratory program was to classify the waste rock sampled during the field program and define the hydrogeological properties of the waste rock. The waste rock samples were classified on the basis of the grainsize distribution results. Grainsize distribution analyses were performed on 96 samples. All samples were dry sieved with out washing. The classification was based on the percentage of material passing the 4.75 mm sieve. Waste rock material was classified into groups containing <10%, 10% to 19%, 20 to 29%, 30% to 39%, and > 50% passing the 4.75 mm sieve. Representative samples of each group were chosen for further laboratory analysis.

Soil water characteristic curves were determined using a large modified pressure plate cell. The pressure plate was capable of handling coarse waste rock containing particle sizes larger than 50 mm. This permitted the use of large representative sample to be used for testing. A 1 bar high air entry disc was used which permitted suction values of up to 100 kPa to be applied.

RESULTS AND DISCUSSION

Waste rock has been placed in the waste rock pile, by end-dumping from several platform elevations, for the past 12 years. The waste rock pile was constructed on the side of a topographic high by end dumping waste rock down the slope. The pile was found to be terraced because several platform elevations were used by haul trucks to end dump waste rock. In general, the crest and toe of the pile was found to gradually build outward at the angle of repose as construction proceeded while the elevation of the platform was maintained relatively constant. Waste rock was either dumped from a platform onto the original ground surface or dumped onto a lower waste rock terrace.

The method of construction of the waste rock dump has controlled the structural orientation observed within the pile. The structure of the dump was found to consist of dipping layers of waste rock material defined by colour and/or grainsize differences. Figure 1 shows a typical exposed bench on the waste rock pile during excavation. The layers are dipping at the angle of repose (approximately 40°) of the material and strike at an angle consistent with the edge of the dump top surface from which the material was end dumped. The layers within the pile ranged from thin lenses (10-20 cm) to wide layers with a thickness of several meters. Waste rock material in the layers may consist of primarily one rock type or may be composed of a combination of rock types.

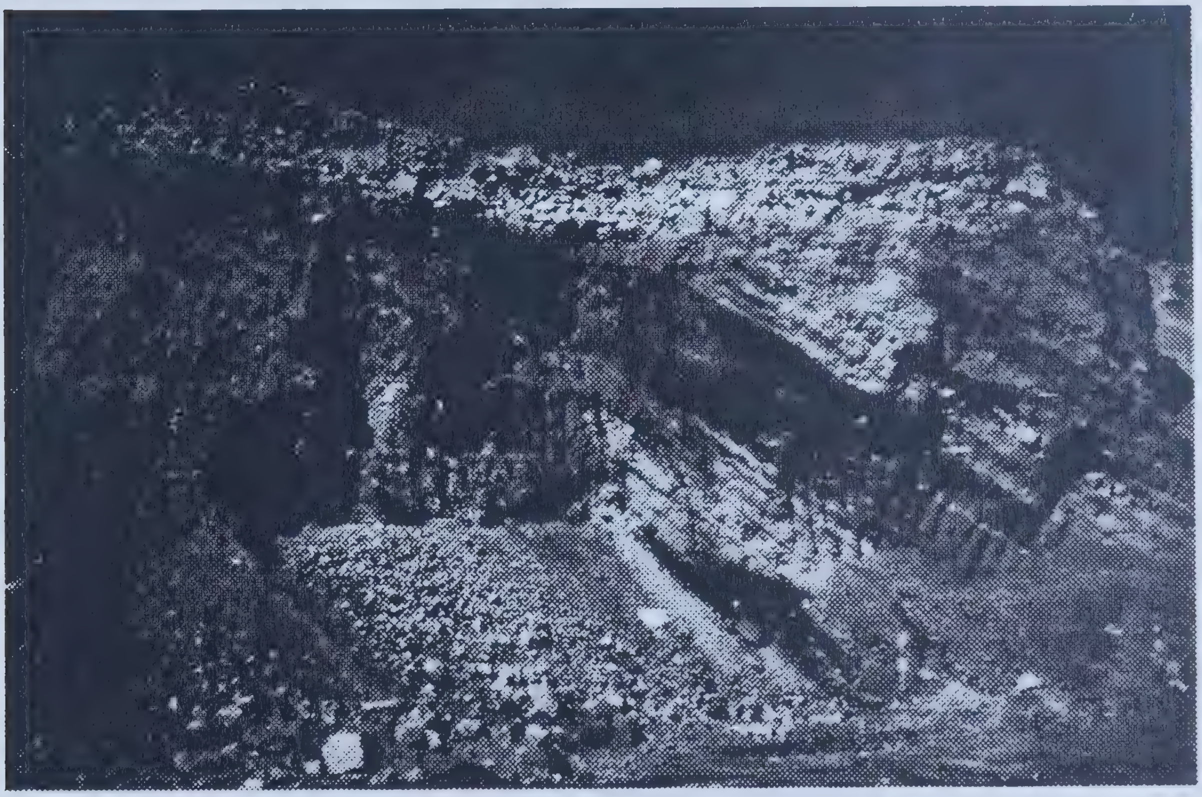

Figure 1 Strong dipping layered structure visible on an excavated section of the pile.

Grainsize differences from very coarse layers with large open interparticle voids and little fines, to fine layers with a significant percentage of silt and sand matrix infilling interparticle voids, were observed. Large changes in grainsize distribution from coarse to fine material were found to occur over adjacent layers marked by sharp contacts dipping at angles consistent with the overall structure within the pile. The fine layers are believed to be either a result of sorting during end dumping or, more likely, due to breakdown resulting from oxidation processes within the pile. A coarse rubble zone exists at the base of the pile in addition to the coarse dipping waste rock layers situated within the pile. Observation from a test pit excavated near the base of the pile as well as evidence from the existing toe of the slope confirm the presence of a coarse rubble zone at the base of the pile. The basal coarse layer is produced as a result of material segregation which occurs along the length of the dump slope.

In general, the upper 10m - 15m of the waste rock pile was found to have a higher moisture content than the material deeper within the pile. A wetting front was observed in the upper portions of the pile which was consistent with data obtained for other waste rock dumps at the site where monitoring equipment had been installed (Schafer et al., 1994). Figure 2 shows gravimetric water contents obtained for the layers sampled in the upper 8m of the waste rock pile. Gravimetric water contents in the upper 10 m range from 4% to 13% compared to 0.5 to 4% below this level.

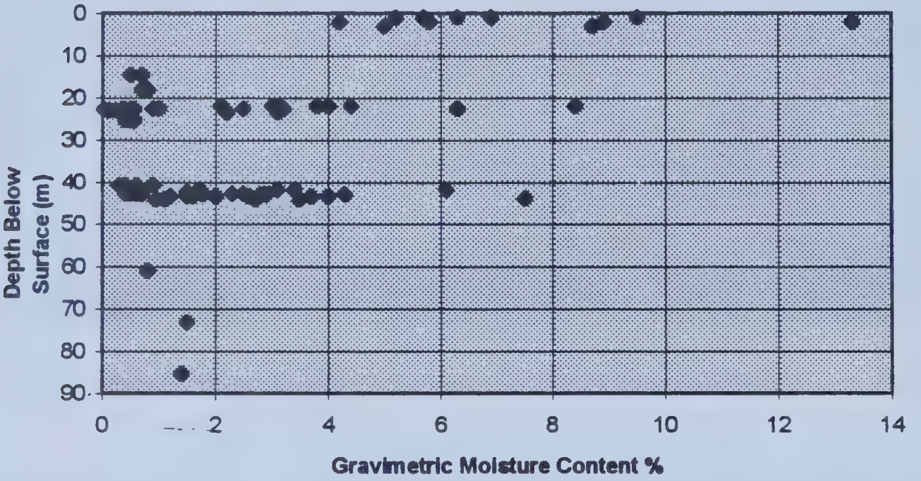

Figure 2 Gravimetric moisture content distribution with depth below waste rock pile surface

The clusters of data at depths of 0m, 23m, and 42m, shown in Figure 2, represent data obtained from different benches. A sharp shift in the clusters of data above 10m defines the wetting front. The wetting front may be the result of two processes. First, infiltration provides water to the wetting front from the surface. This is believed to be the dominant process. However a secondary source of water may also be delivered to the upper zones of the wetting front due to the upward movement of water from deeper within the pile through vapour transport. Convective air flow and vapour transport occurs in waste rock piles due to elevated temperatures associated with oxidation of pyrite in the waste rock. Venting of warm moist air has been frequently observed at this site. The coarse dipping layers appear to be important pathways for the venting of warm moist air. Temperatures of a coarse permeable layer with visible venting were measured as high as 65° C with relative humidity values of 100%. Numerical simulations have also shown this process can be a significant transport mechanism in waste rock piles (Lefebvre and Gélinas, 1995).

Most of the venting and transport of warm moist air appears to be restricted to the upper portion of the waste rock pile. Studies of other piles at the site show increased temperatures in the upper portion of the pile where the wetting front is well developed. Temperature measurements taken during the field program averaged 30° C in the wetting front where the higher water contents were detected. Temperature values below the wetting front averaged 20° C. It appears that the water content of waste rock below this level is too low to support bacterial oxidation (Schafer et al., 1994). The bacteria Thiobacillus Ferrooxidans accelerate the oxidation of sulfide minerals resulting in elevated temperatures.

Field mapping and grainsize distribution analyses revealed that waste rock with a wide range of physical characteristics can be found within the pile. Material with a grainsize distribution ranging from >50% to < 2% passing the 4.75 mm sieve was found in the dipping layers in the waste rock pile. Particles with a maximum particle size of several meters also occur with in the pile. This range of physical characteristics in conjunction with the steeply dipping layers produces a highly heterogeneous and structured waste rock pile. Grainsize distribution curves were used to classify the waste rock samples obtained from the field program for further laboratory analysis.

The physical and hydrogeologic properties within the pile must be characterized in order to understand how water moves and transports solutes within an unsaturated, heterogeneous waste rock pile. For unsaturated materials the moisture content and hydraulic conductivity are a function of the suction in the soil. The soil water characteristic curve is critical to understanding how water flows and is stored within the unsaturated pile. The soil water characteristic curve describes the relationship between water content and the suction of the soil. The capacity of a material to store water is a function of the soil suction and the physical characteristics of the material. The volume of water that enters or is released from the material with a change in pore water pressure is described by the slope of the soil water characteristic curve. Direct measurement of unsaturated hydraulic conductivity is difficult and the hydraulic conductivity versus suction curve is commonly determined from the soil water characteristic curve.

A comprehensive literature search reveals little data on the soil water characteristics of waste rock material is available. There is currently a need for further characterization of unsaturated flow in heterogeneous waste rock in order to improve the modelling capabilities for the physical processes active in waste rock piles (Blanchette, 1992).

The soil water characteristic curves are currently being determined for samples representing several groups of samples classified on the basis of the grainsize distribution. The objective is to establish the soil water characteristic curves for samples ranging from the finest grained waste rock to the coarse samples which contain little to no fines. The range of soil water characteristic curves will provide the basis for analyzing the variation in hydrogeologic properties for the various waste rock types found in the structured, heterogeneous pile.

Figure 3 illustrates a soil water characteristic curve for fine grained waste rock with over 50% passing the 4.75 mm sieve. A soil water characteristic curve for gravel has been included for comparison purposes (Machibroda, 1994). The curve for fine grained waste rock, shown in Figure 3, represents the finest waste rock material found in the pile during the field program.

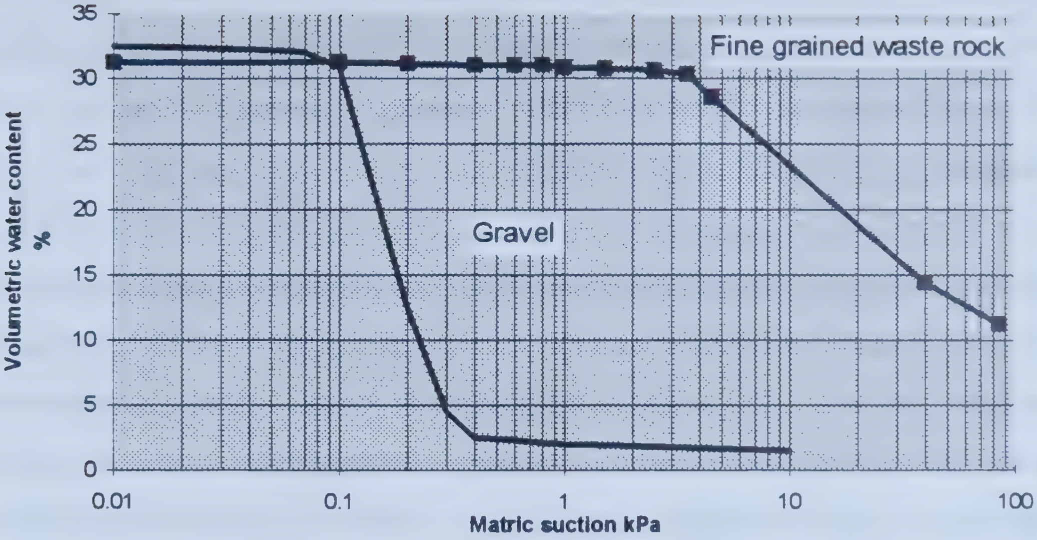

Figure 3 Soil water characteristic curves for gravel (Machibroda, 1994) and fine grained waste rock.

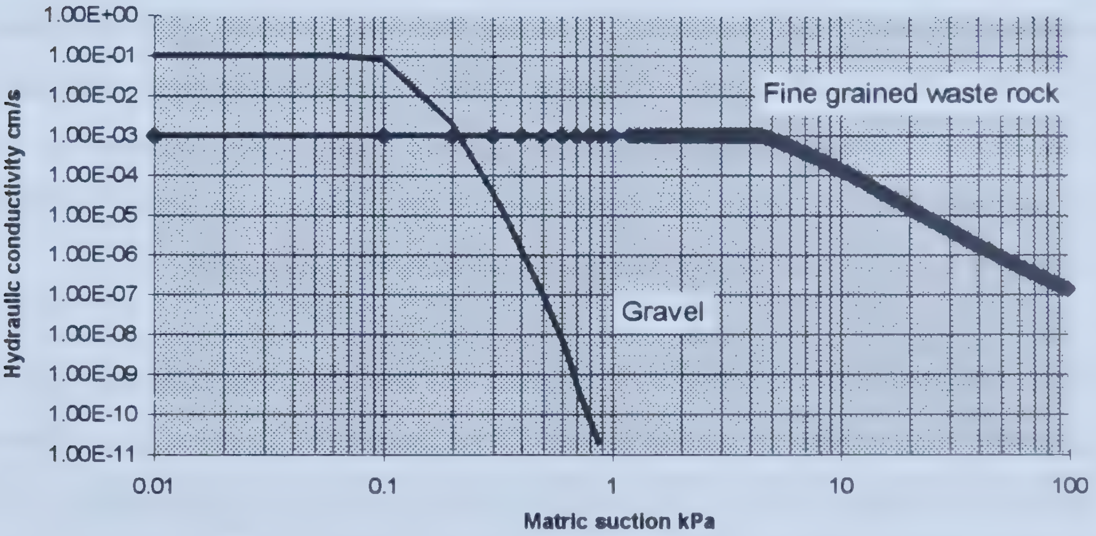

Figure 4 Relative hydraulic conductivity versus matric suction for coarse crushed rock (Machibroda, 1994) and fine grained waste rock.

When the soil water characteristic curve for the fine waste rock is compared to gravel it is clear that for suctions greater than 0.1 kPa the fine waste rock is capable of retaining a higher volumetric water content. Coarse waste rock, like gravel, can be expected to have a lower air entry value and drain rapidly under applied suction when compared to the fine waste rock. The soil water characteristic curve for gravel shows an air entry value of 0.1 kPa compared to an air entry value of 4 kPa for fine grained waste rock. In other words, the coarse waste rock will have very little capability of storing water under negative water pressures.

Figure 4 shows the relationship between hydraulic conductivity and suction for gravel and fine grained waste rock. A saturated hydraulic conductivity of 1x 10^{-3} cm/s is assumed for the fine waste rock. The ability to transmit water in unsaturated conditions is dependent on the number of pore channels containing water. Pores containing water provide conduits or channels for liquid water flow. In saturated conditions, all pores are available for flow. In unsaturated conditions, not all pores are filled with water. When unsaturated, the larger drained pores are not available for liquid water flow and the hydraulic conductivity decreases significantly. Figure 4 shows that the hydraulic conductivity of the fine waste rock is higher than the gravel at values of matric suction exceeding 0.2 kPa. The fine waste rock stores more water at higher values of matric suction and therefore transports liquid water more readily when compared to the gravel. In summary, the fine waste rock layers provide the pathways for liquid water and solute transport in the waste rock pile when unsaturated conditions prevail.

Upon completion of the laboratory program, the soil water characteristic curves and the hydraulic conductivity vs. suction curves will be determined for the range of material types found in the pile. This data will provide the basis for determining the storage characteristics of the waste rock pile and the pathways for water flow and solute transport.

CONCLUSION

The current understanding of the hydrogeologic processes in waste rock piles needs to be developed further. A better understanding of the hydrogeology will improve the ability to predict the physical processes which affect acid rock drainage in unsaturated heterogeneous waste rock piles. The partial excavation of a large waste rock pile has provided the opportunity to conduct research for the characterization of the physical and hydrogeologic properties of a waste rock pile built over the past twelve years.

The waste rock pile was found to have a well defined structure consisting of dipping beds defined by either colour and/or changes in grainsize. The structure is a result of the angle of repose end-dump construction method. The structure and heterogeneity within the pile affects the water flow and solute transport processes. Samples taken from the field have been characterized on the basis of grainsize distribution. A laboratory program is currently underway to determine the soil water characteristic curves and hydraulic conductivity vs. suction relationships for the various groups of waste rock material classified. The hydrogeologic properties determined are critical in defining the water storage characteristics and the pathways for unsaturated liquid water flow in the pile. The results of the field logging and laboratory programs are intended to provide the physical and hydrogeologic framework for an improved understanding of the heat and mass transfer processes that affect acid rock drainage in large waste rock piles.

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Environmental Management For Mining

Reclamation Certification Criteria: Balancing Competing Interests

Chris Powter and Neil Chymko

Alberta Environmental Protection,
Land Reclamation Division,
3rd Floor, 9820 - 106 Street,
Edmonton, Alberta
T5K 2J6

RECLAMATION CERTIFICATION CRITERIA: BALANCING COMPETING INTERESTS

Chris Powter and Neil Chymko

Alberta Environmental Protection, Land Reclamation Division
Edmonton, Alberta

Abstract

Alberta's *Environmental Protection and Enhancement Act* requires operators to conserve and reclaim land and to obtain a reclamation certificate. The government, in cooperation with industry and other stakeholders, has developed reclamation certification criteria for wellsites and for railways. Criteria are being developed for pipelines, sand and gravel pits, roadways, and other activities. The criteria measure the success of industry's efforts to return disturbed land to equivalent land capability. Factors such as activity type and size, age of the disturbance, geographic location, need for consistency and at the same time flexibility, need for equal treatment between and within industries, administrative and technical simplicity, and stakeholder views are considered when developing the criteria. Some of these factors conflict with each other. This paper describes how the factors are weighed in developing the final criteria.

Key Words: Reclamation criteria; wellsites; pipelines; stakeholders

Introduction

Alberta's *Environmental Protection and Enhancement Act* (EPEA) came into force September 1, 1993. EPEA requires operators of specific industrial developments to conserve and reclaim land and to obtain a reclamation certificate. The activities covered include coal mines, oil sands mines, quarries, sand and gravel pits, pipelines, wellsites, railways and roadways.

The *Conservation and Reclamation Regulation* gives the Director the ability to establish criteria for certification. It also lays out the information that must be submitted with an application for a certificate.

The objective of reclamation in Alberta is the return of equivalent land capability. This means that the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being carried conducted on the land, but that the individual land uses will not necessarily be the same. The intent is to retain the original range of land use options for future generations. At the same time, there is flexibility to change the capability for various land uses (e.g., good forestry capability can be replaced by good wildlife capability).

In general, the land uses before and after development are the same, especially on smaller disturbances such as wellsites and linear disturbances such as pipelines. However, the land use can be different if all stakeholders agree. Thus criteria for reclamation certification must be flexible and able to address a variety of potential land uses.

To date we have developed and published criteria for wellsites (*Reclamation Criteria for Wellsites and Associated Facilities*). Criteria for railways are ready to be released but require an amendment to the regulations before they can be published. Criteria for sand and gravel pits, pipelines and roadways are being developed and should be available in 1996.

Development and Implementation of the Criteria

Alberta Environmental Protection (AEP) develops criteria jointly with our partners in industry and the affected publics. Stakeholder committees prepare draft criteria. When they are finished, the draft criteria are sent for review and comment to a variety of stakeholder groups. These groups represent industry and landowners who have a direct interest in land reclamation. The criteria are redrafted based on their comments and are published. The criteria are then tested for a period of time. Periodic reviews of the effectiveness of the criteria are conducted and revisions made if necessary.

In the case of the wellsite criteria, courses were developed jointly between government and industry. The Petroleum Industry Training Service delivered the courses to people who would be using the criteria to evaluate sites. The private sector also offered courses.

Need for Criteria

Criteria provide industry with a clear understanding of the government's expectations for reclamation. This allows industry to plan their activities with the "target" in sight. After a site has been reclaimed, the criteria allow reclamation success to be measured. Finally, the criteria allow government, industry and consultants to train their staff in the certification process and requirements.

Interpreting Criteria: Consistency vs. Flexibility

Criteria also help to ensure that industry's reclamation efforts will be evaluated the same way by different government inspectors. The need for consistency between inspectors was a key factor in industry's request for criteria.

At the same time, inspectors are encouraged to use professional judgement when faced with site specific issues. Industry is allowed to submit reclamation applications when sites do not exactly meet the criteria if they can justify the reasons for variation.

This combination of consistent application of criteria combined with a flexible interpretation by field staff ensures that reclamation objectives are met. It also ensures a fair regulatory system for industry.

Kinds of Criteria

Alberta has considerable experience with reclamation of agricultural land and forested land. With this knowledge base, we were able to design criteria to assess the characteristics of these kinds of lands. However, as noted above, there are times when the land use may change; for example, to a lake or wildlife habitat. We have not developed detailed criteria for these kinds of lands.

To date, most of the certification of lakes and wildlife habitat has been done on sites with approvals. For example, TransAlta Utilities, regional stakeholders and the government jointly developed the design of East Pit Lake at the Whitewood coal mine. When the lake was completed and the site revegetated, the company submitted detailed information on the lake (e.g., water temperature and chemistry, vegetation surveys, fish growth rates, etc.) and requested a reclamation certificate. The certificate was granted after a careful review of the site conditions relative to the approved plan and several site inspections. In addition, the physical, chemical, and biological data were also evaluated to ensure the lake was a viable waterbody.

Approvals vs. Criteria

Certain activities require approvals from the Department before they can be developed. In the approval process, the company and government agree to the conservation and reclamation methods to be used on the site. The company's plan and the approval conditions meet the intent of the reclamation criteria. The plan provides the opportunity for refinement of the criteria to meet the site specific conditions of the project. As a result of this agreement, measuring the company's reclamation success is based on adherence to the site specific plan, rather than on a set of criteria.

Landscape vs. Soil vs. Vegetation

The criteria developed to date evaluate three main components of a reclaimed site: landscape, soils and vegetation. Preference is not given to one or the other. The criteria for wellsites do allow the inspector to waive the need for a soils assessment on sites that fall into the Grassland category if the vegetation has been established for three years. The inspector may request soils information if it appears that the company has not replaced all available topsoil.

Field Assessment vs. Laboratory Assessment

When criteria were developed for wellsites there was considerable debate regarding the role of soil analysis in reclamation certification. Analytical tests were suggested for determining organic matter content, salinity, and contaminants.

After much discussion it was agreed that field assessments of soils and vegetation would be adequate for the majority of sites. If problems are suspected on a site, the inspector may ask the company to do soils analyses to identify the nature and extent of the problem.

The reclamation criteria we have developed to date state that all contamination must be remediated **before** an operator applies for certification. Criteria for contaminant remediation (e.g., *Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation*) are provided by the Chemicals Assessment and Management Division of AEP.

Simplicity vs. Technical Detail

Once the decision was made to use field assessments to judge reclamation success, the debate centred on the nature of the assessments to be performed. Ideally, professional soil and vegetation specialists would be employed by each company to evaluate each reclamation site. However, we do not live in an ideal world.

Thus the criteria strike a balance between simple measures (e.g., topsoil depth) requiring little training (except for the ability to determine what topsoil is when confronted with admixed soils or mixed soil layers) and more complex measures requiring some soils knowledge (e.g., soil texture). Vegetation assessments are based on a combination of measurements (e.g., plant height) and visual estimates (e.g., percent cover and percent composition). Landscape assessments are all based on visual estimates.

In all cases, if there is a difference of opinion between the company's assessment of the site and the inspector's, the company would be expected to provide measured, rather than estimated, data.

Generic Criteria vs. Industry-Specific Criteria

Criteria are being developed for each industry taking into account the nature of their disturbance. The objective of equivalent land capability is the same for all industries, as is the general format (i.e., landscape, soils, vegetation parameters) of the criteria. The differences in criteria relate mainly to the extent of information and sampling required (e.g., number and location of samples) to evaluate reclamation success.

In the case of railways, the criteria recognize that the railbeds have been in place so long that land use has adapted to their presence (e.g., new water courses have developed). Thus removal of the railbed is not required for certification. The same will likely hold true for roadways.

Regional vs. Province-Wide Criteria

Province-wide criteria would be the simplest to develop and implement, however they would not address the variability in Alberta's soils, vegetation and land uses.

The wellsite criteria have five separate categories: cultivated land, grasslands, forested land with cultivation potential, other forested land, and peatland. The criteria for these categories differ in the level of assessment required to show the objective of equivalent capability has been met.

Time of Construction vs. Time of Abandonment

Many of Alberta's industrial sites were constructed many years or decades ago. At the time of construction there may have been no requirement for topsoil conservation or reclamation. Thus the criteria recognize that older disturbances can have lower expectations for reclamation success that newer ones. These sites, however, are still expected to meet some level of reclamation success.

For example, the wellsite criteria recognize three construction dates: prior to 1983, when topsoil salvage was not enforceable; 1983 to 1994, when salvage was required but no written criteria were in place; and after 1994 when the criteria were put in place.

Conclusions

Reclamation criteria provide clear, achievable, and measurable targets for industry. They provide a framework for industry to develop plans for construction, operation and reclamation of their sites. The criteria format serves as a basis for development of criteria for other industries. They also allow government, industry and consultants to be trained to evaluate reclamation success.

To date, Alberta has successfully developed criteria through a process where industry, government and other stakeholders work together. As a result, all stakeholders "own" the criteria. Once developed, the effectiveness of the criteria are evaluated by all stakeholders and are reviewed from time to time to determine if changes are required.

The criteria are tailored to each industry and account for the differences in Alberta's diverse soils, vegetation and landscapes. Within the criteria for each industry sector, there is flexibility for consideration of site-specific issues. At the same time, they ensure the objective of equivalent land capability has been met.

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Proposed Tailings Management at the McClean Lake Project: Designing for Decommissioning

By:

Daren W. Willems
Environment Coordinator, McClean Lake Project,
Cogema Resources Inc.
817-825 - 45th Street W. Saskatoon Sk. S7K 3X5

and

Alain Marvy, Vice President
Cigar Lake Mining Corporation.
410-224 4th Ave S. Saskatoon, Sk.

PROPOSED TAILINGS MANAGEMENT AT THE McCLEAN LAKE PROJECT: DESIGNING FOR DECOMMISSIONING

Daren Willems and Alain Marvy

Abstract: Cogema Resources Inc. (Cogema) is currently developing the McClean Lake Project in Northern Saskatchewan. The development includes the mining of several uranium ore bodies and the construction and operation of an associated mill and tailings depository. The proposed tailings depository consists of tailings deposition into a mined out open pit, similar to the existing in-pit "pervious surround" method employed at Cameco's Rabbit Lake mine. However, due to the high grade of the Project's tailings, several modifications were made to the original design of the tailings facility and the tailings placement methodology. These modifications will provide the necessary radiation and environmental protection required for handling and placement of high grade tailings.

The modifications made to the "pervious surround" disposal concept include the deposition of tailings as a thickened (engineered) paste below a water cover and the incorporation of a unique groundwater pumping methodology which provides "hydrodynamic containment" of porewater expressed during consolidation. In addition these measures will ensure that tailings density is maximized and the hydraulic conductivity of the tailings mass is minimized by the end of operations. The provision of a water cover also eliminates consolidation problems associated with freezing. At the completion of milling activities, a soil cover will be placed above the tailings surface to consolidate the most recently deposited tailings and to provide a permanent barrier between the tailings and the terrestrial environment. At the time groundwater conditions are restored to pre-mining levels (flood back of the cone of depression), the tailings will be sufficiently consolidated, resulting in a low permeability tailings mass (ie. plug) contained within a higher permeability host rock. Contrasting permeability's will cause groundwater to flow around the tailings mass rather than through it, similar to that of the pervious surround system. The subaqueous thickened tails deposition will ensure that decommissioning activities can proceed shortly after tailings placement with a minimal release of heavy metals and radionuclides to the environment.

Introduction

The McClean Lake Project is located in northern Saskatchewan, approximately 750 km north of Saskatoon (Figure 1). The development includes the mining of several uranium ore bodies, and the construction and operation of an associated mill and tailings depository. In addition to milling McClean Lake project ores, ores from the nearby Midwest and Cigar Lake project sites are proposed for processing at McClean Lake in a joint effort between mining companies to reduce the number of mills and tailings facilities in Northern Saskatchewan. This was in part motivated by the fact that fewer mills and tailings depositories would result in fewer environmental impacts to the northern region of Saskatchewan.

Tailings management at McClean Lake is considered by Cogema to be a high priority in terms of environmental and radiation protection. To ensure optimum protection, the tailings handling and disposal methodology at the McClean Lake JEB Tailings Management Facility was designed to:

- limit the exposure of workers and the general public to radioactive wastes;
- minimize the leaching of radionuclides and heavy metals to the environment;
- ensure ease of operation and rapid decommissioning through design optimization; and
- limit or prevent the need for continued maintenance after closure.

The proposed tailings disposal concept utilizes the mined out JEB open pit as a tailings disposal facility, similar to the existing in-pit pervious surround system employed at Cameco's Rabbit Lake mine. Upon completion of mining, preparation of the pit for tailings will begin, consisting of the construction of a granular underdrain, horizontal drift and a vertical raise.

Initially, the Pervious Surround Method was selected and approved as the best suited tailings management system for the containment of McClean Lake and Midwest tailings (approved for the McClean Lake Project in 1993), however concerns remained in regards to the formation of ice lenses in the tailings mass and fugitive dust emission. In consideration of the high-grade Midwest and newly incorporated Cigar Lake tailings, there was also a concern of a net increase in radiation exposure which would require additional radiation protection measures for workers within the vicinity of the JEB tailings management facility. These concerns led to the modification of the approved JEB "Pervious Surround System", by changing it to a paste underwater tailings disposal facility, which is also based on the same long term containment and flow diversion concept.

By the newly proposed "paste underwater" method, the tailings will be deposited in a thickened paste form under a cover of water. The mode of tailings placement and the unique tailings management methodology will provide containment of expressed tailings porewater, while maximizing the density and minimizing the hydraulic conductivity of the tailings mass during the operational phase. The provision of a water cover above the tailings provides a shield against gamma radiation, prevents dust emissions and reduces radon emanation. In addition, the water cover eliminates consolidation problems associated with freezing by preventing the formation and accumulation of ice lenses. The thickened tailings provides more predicable and homogeneous tailings properties which prevents solids segregation which is common to traditional slurry deposition techniques. At the completion of milling activities, a soil cover will be placed above the tailings mass to assist in consolidation and provide permanent containment. Collection and treatment of tailings porewater will continue for a few years after cover placement.

Environmental Considerations Arising from Cigar Lake Mining Corporation's Testwork

Numerous studies were performed on behalf of the Cigar Lake Mining Corporation (CLMC), which led to the concept of "paste tailings underwater disposal", as well as to various environmental recommendations pertaining to the milling and tailings disposal process. In their studies, CLMC not only considered an "engineered storage facility" but went a step further and considered "engineered tailings", integrating design considerations into the milling process to enhance the operability and environmental aspects of tailings management.

In the tailings testwork, extensive efforts were devoted to determining the most effective techniques available to consolidate the tailings without adversely impacting worker exposure to radiation. Testing demonstrated that paste tailings could be created by a "deep thickener" which produced a product in the range of 38 to 48% solids. The paste tailings can be pumped to a tailings disposal facility and subaqueously deposited without mixing with the overlying water, similar to the underwater placement of concrete.

Paste Tailings at Cluff Lake Operations

Although subaqueous paste tailings disposal is a relatively new concept, paste tailings are already being produced at Cogema's Cluff Lake operations, since February 1995. Through this work, Cogema has demonstrated on an industrial scale the feasibility of preparing and pumping paste tailings.

Proposed Tailings Management System

The evaluation of the JEB pit tailings management facility as a subaqueous disposal system was based on the testwork conducted by the CLMC for Cigar Lake ores and on the testwork conducted by Cogema (SEPA) for the McClean Lake and Midwest ores.

Optimization of the performance of the proposed JEB tailings management facility was based upon:

- the subaqueous deposition of paste tailings;
- enhanced tailings consolidation due to the pumping of the tailings (consolidation) porewater from the underdrain, and;
- the incorporation of a soil/ waste rock cover to be placed above the tailings at decommissioning.

Tailings Characterization

The proposed paste tailings produced at the JEB mill will consist of water and fine solid particles at a solids content approaching 40%. The fine particles in the paste mixture are comprised of mine tailings or naturally-occurring clays, silts and fine sands. The mineralogy of these particles range from quartz and feldspars to clays, micas, salts and chemical precipitates. The fine and ultrafine particles will provide stability by preventing rapid settling and particle size segregation.

The paste mixtures are Bingham fluids whose apparent viscosity is not constant but decreases considerably with increasing shear rates. The paste tailings gradation is dominated by particles in the medium to very fine size fraction with only about 15% of the particles exceeding 0.2 mm in size. Consequently, paste flows in pipes can be assumed to remain basically homogenous. Practical experience from other programs has indicated that pastes can remain motionless in pipelines for several days and can then be remobilized without pipeline plugging occurring.

Preparation of the Pit

Following excavation and mining of the JEB orebody, the JEB pit will be prepared for use as a tailings management facility. The tailings management facility will include the installation of a drift and raise, and the placement of a basal underdrain consisting of blast rock and free draining granular filter material, as illustrated in Figure 2. The horizontal drift will be backfilled with sufficiently coarse rock and hydraulically connected to the drift. The collection of consolidation flows during operations and a few years immediately after operations will be collected from the raise. The pit will be maintained in a fully dewatered state prior to the placement of tailings.

Operational Sequence

Paste tailings will be deposited subaqueously under a water cover (up to 10 m in thickness) throughout the tailings placement phase of the JEB tailings management facility operations. The paste tailings will be pumped from the mill facility to a floating barge on the ponded water within the tailings management facility. Tailings will be subaqueously placed through a tremie pipe attached to a rotational placement boom assembly located on the barge (Figure 2). The tremie pipe will inject fresh tailings into previously deposited tailings at the tailings surface in the same manner in which concrete is placed under water. This application ensures that the tailings do not mix with ponded water during placement thus maintaining paste consistency, density and homogeneity.

Water Management

Water management is a key component in the operation of the tailings management facility. It includes the groundwater surrounding the pit, ponded water above the inpit tailings and porewater expressed from the tailings during consolidation. The control and management of water resources will be provided by integrated pumping from the perimeter dewatering wells, the underdrain drift and raise and from the pond. Groundwater inflows into the pit will be controlled primarily by the perimeter dewatering wells where hydraulic head will be maintained throughout tailings placement at a level approximately 2 m above ponded water level (to provide hydrodynamic containment). In addition, a downward vertical gradient will be maintained between the pond level and the water level in the underdrain sump which will ensure the collection of tailings porewater (resulting from consolidation) in the underdrain for subsequent treatment. Water levels (head) in the underdrain will be permitted to rise with ongoing tailings placement. The proposed containment philosophy will allow all groundwater to flow towards the underdrain where it is collected and subsequently treated. Collection and treatment of the underdrain water will minimize the operational impacts to the surrounding groundwater and downgradient receptors. The need for hydrodynamic containment will diminish when adequate consolidation is achieved near the end of operations. Figure 3 illustrates the proposed water management methodology for the JEB pit tailings management facility.

Water will be collected from the underdrain, perimeter wells and the pond via piping systems. Clean and contaminated (if any) water will be collected in independent pipelines from the perimeter dewatering wells and directed either directly to the treated effluent disposal area or to the water treatment plant. All water pumped from the pond and underdrain sump through operations will require treatment prior to discharge to the environment.

Tailings Consolidation

Immediately following placement, the tailings will undergo self-consolidation resulting from inherent selfweight. Since the tailings are produced in a paste form with a low moisture content, the time required for consolidation will be minimized. In addition, the water management strategy described above will excellerate the consolidation process, resulting in a high degree of consolidation by the end of operations. Consolidation will continue with ongoing tailings displacement and the placement of the final cover at closure.

Results from tailings consolidation analyses predict that the elevation of the final consolidated tailings mass will be within the in-pit bedrock, a few years following placement of the cover. The total quantity of tailings to be deposited, estimated at 3,000,000 tonnes and a total volume of 3.26 million m^3 results in an estimated average dry density of 910 kg/m^3 and a maximum dry density of 1080 kg/m^3 (at the base of the pit).

Decommissioning

At the completion of tailings placement, the ponded water within JEB pit will be pumped to the water treatment plant for treatment to meet the Metal Mining Liquid Effluent Regulations. A minimum depth of ponded water will be left above the tailings surface to provide radiation protection. A 3 m thick granular filter layer will be placed on top of the tailings surface to permit the collection of porewater expelled during the consolidation of the most recently deposited tailings due to both self weight and cover loading. Following placement of the filter and drainage layer, the pit will be backfilled with excavated drift and sandstone materials to an elevation slightly above ground surface.

A vertical raise will be installed through the backfilled material from ground surface down to the upper drainage layer. This will provide for the collection of consolidation flows which will originate in the most recently deposited tailings in the upper portion of the pit, largely due to the surcharge loading of the cover material. Concurrent pumping from the underdrain and upper drainage layer (at base of cover) will be continued until consolidation flows have been reduced to a level where long term impacts to the environment will be acceptable; this period is estimated to be up to 5 years following the placement of the cover. The surcharge loading will enhance the degree of consolidation of the tailings mass and result in a lower rate of contaminant release over the long term due to porewater expulsion.

Groundwater Flow and Contaminant Transport Simulations

Computer modelling was used to establish the groundwater flow regime and to determine the mass transport of contaminants from the tailings facility. Groundwater modelling was first used to identify the potential transport pathways to receptors and to estimate flowrates. Contaminant transport modelling then focused on determining, firstly, the total mass of contaminant leaving the JEB tailings management facility and, secondly, the concentration and total mass transport predicted to reach the primary receptors, Fox Lake and Pat Lake, through the groundwater pathway.

A detailed groundwater flow model was set up using MODFLOW[1] to simulate the groundwater flow from the proposed JEB tailings management facility. Particle tracking analysis was conducted using MODPATH to evaluate advective groundwater flow paths from the tailings management facility. Long-term advective and diffusive contaminant transport from the decommissioned JEB tailings management facility, was then simulated using MT3D.[2]

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[1] MODFLOW is a quasi-three dimensional finite difference simulation of groundwater flow within a porous media developed at U.S. Geological Survey.

The MODFLOW model utilized conservative assumptions with respect to the hydraulic conductivity of the drift and the continuity of fault zones between the pit and Fox and Pat Lakes. Figure 4 illustrates the geological strata and the material properties used in the MODFLOW analysis. The MT3D model used conservative and constant source terms assuming no source depletion for the duration of the simulations. In consideration of these conservative assumptions, long-term environmental loadings to surrounding surface water receptors are likely less than predicted herein by the mass transport simulations.

The particle tracking results (Figure 5) illustrate that the majority of groundwater flow that passes through the pit area is directed toward the east arm of nearby Fox Lake. In the long term post-decommissioning period, only a very small portion of groundwater flowing towards Fox Lake will have originated from within the tailings mass while most will have originated from outside of the tailings. This is due to the high in situ permeability of the Athabasca Sandstone and the relatively low permeability of the consolidated tailings. The relatively high in situ permeability of the altered sandstone (1.8×10^{-6} m/s) in comparison to the consolidated tailings mass (1×10^{-8} m/s to 3×10^{-7} m/s), will serve as a natural pervious surround diverting flows around the tailings mass while minimizing advective flow gradients through the tailings mass.

Transport analysis were undertaken for arsenic, radium-226 and sulphate. Other chemical constituents including uranium, cadmium, copper, lead, nickel, and zinc were not assessed due to low mean source concentrations relative to the Saskatchewan Surface Water Quality Objectives (SSWQO).

The transport simulations indicated that for the parameters modelled, the fully mixed concentrations in Fox Lake and Pat Lake (downstream of Fox Lake) would be well below the Saskatchewan

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[2] MT3D is a computer model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater flow systems in either two or three dimensions. MT3D uses a mixed Eulerian-Lagrangian approach to the solution of the advective-dispersive-reactive equation.

Surface Water Quality Objectives (SEPS 1988) at concentrations of at least 200 times less for radium-226 and 60 times less for arsenic. The tailings depository is expected to have a negligible impact on the long-term water quality of downstream Collins Creek.

Conclusion

The proposed subaqueous paste tailings disposal system and associated operating methodology for the McClean Lake Project is well suited for the local hydrogeological conditions and the proposed tailings characteristics. Subaqueous disposal minimizes radiation exposure and dust emissions and eliminates consolidation problems associated with freezing. Paste thickening of the tailings and the tailings placement methodology will prevent solids segregation and promote homogeneity and isotropy within the tailings mass. Milling the ore to controlled specifications will produce "engineered" tailings which will allow the short and long term behaviour of the tailings to be predicted with a higher degree of accuracy and confidence than for tailings deposited by traditional slurried disposal methods. The use of engineered tailings, the use of subaqueous disposal techniques and the incorporation of the proper water management methodology will ensure that environmental protection and worker and public safety will be maintained. In addition, these principles will ensure more rapid decommissioning of the JEB tailings management facility at closure.

Acknowledgments

Clifton Associates Ltd. and Golder Associates were the primary consultants involved in the technical studies and assessment which support tailings management at McClean Lake.

References:

1. Saskatchewan Environment and Public Safety (SEPS), 1988. Saskatchewan Surface Water Quality Objectives. Water Quality Branch, WQ110.

Figures:

Figure 1 Location of the McClean Lake Project

Figure 2 Cross-section of the JEB Tailings Management Facility

Figure 3 Water Management Strategy

Figure 4 Local Stratigraphy including Material Properties used in the Analysis

Figure 5 Contaminant Transport Pathways

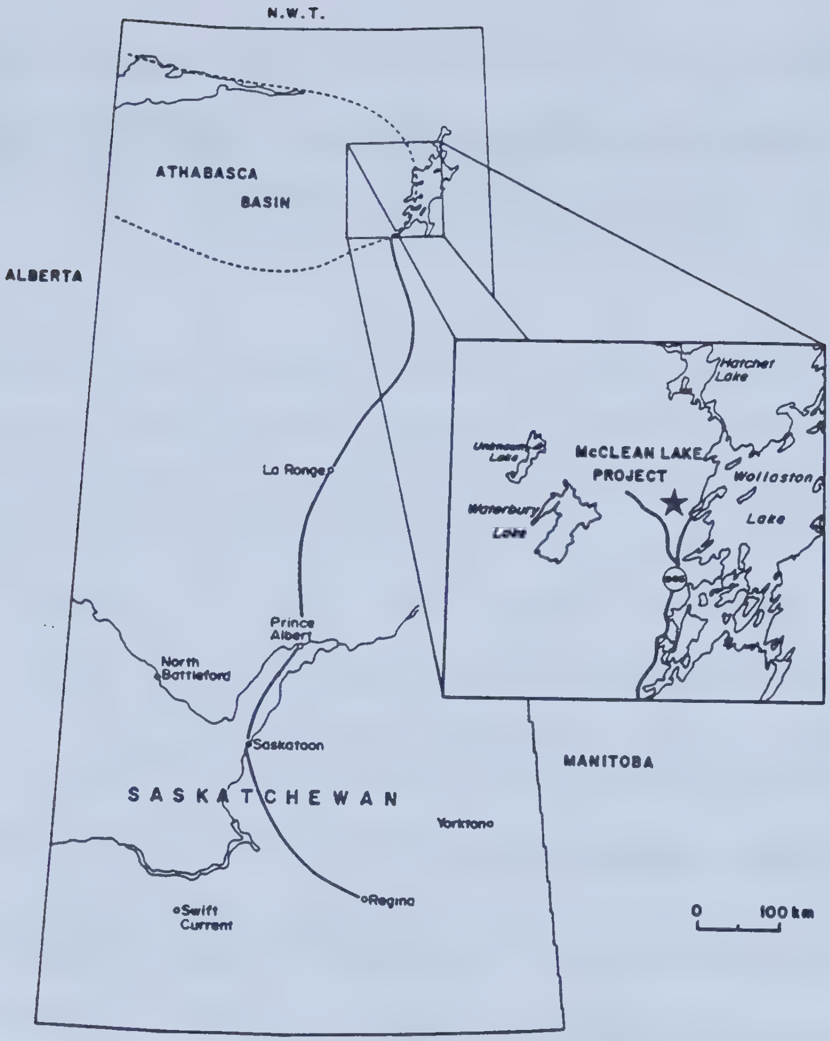
N.W.T.
ATHABASCA
BASIN
ALBERTA
La Ronge
Prince Albert
North Battleford
Saskatoon
SASKATCHEWAN
Yorkton
Swift Current
Regina
MANITOBA
0
100 km
Hatchet Lake
Unknown Lake
McCLEAN LAKE PROJECT
Wollaston
Lake
Waterbury Lake

Figure 1 Location of the McClean Lake Project

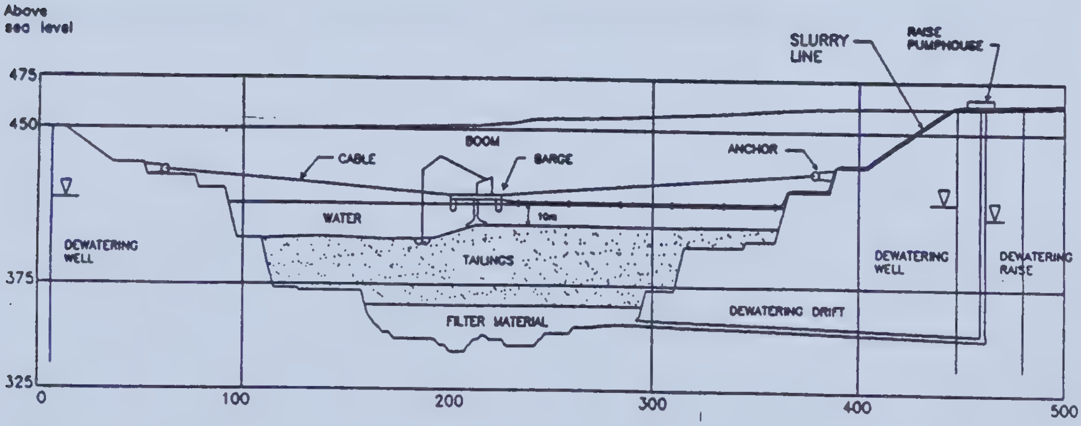
Above sea level
475
450
375
325
0
100
200
300
400
500
SLURRY LINE
RAISE PUMPHOUSE
BOOM
CABLE
BARGE
ANCHOR
WATER
10m
DEWATERING WELL
TAILINGS
DEWATERING WELL
DEWATERING RAISE
DEWATERING DRIFT
FILTER MATERIAL

Figure 2 Cross-section of the JEB Tailings Management Facility

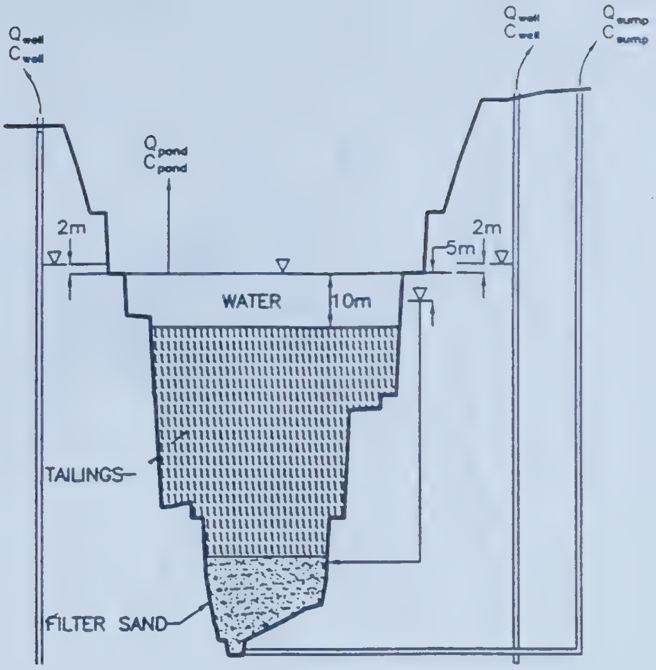
Q_{well}
C_{well}
Q_{pond}
C_{pond}
Q_{well}
C_{well}
Q_{sump}
C_{sump}
2m
2m
5m
WATER
10m
TAILINGS
FILTER SAND

Figure 3 Water Management Strategy

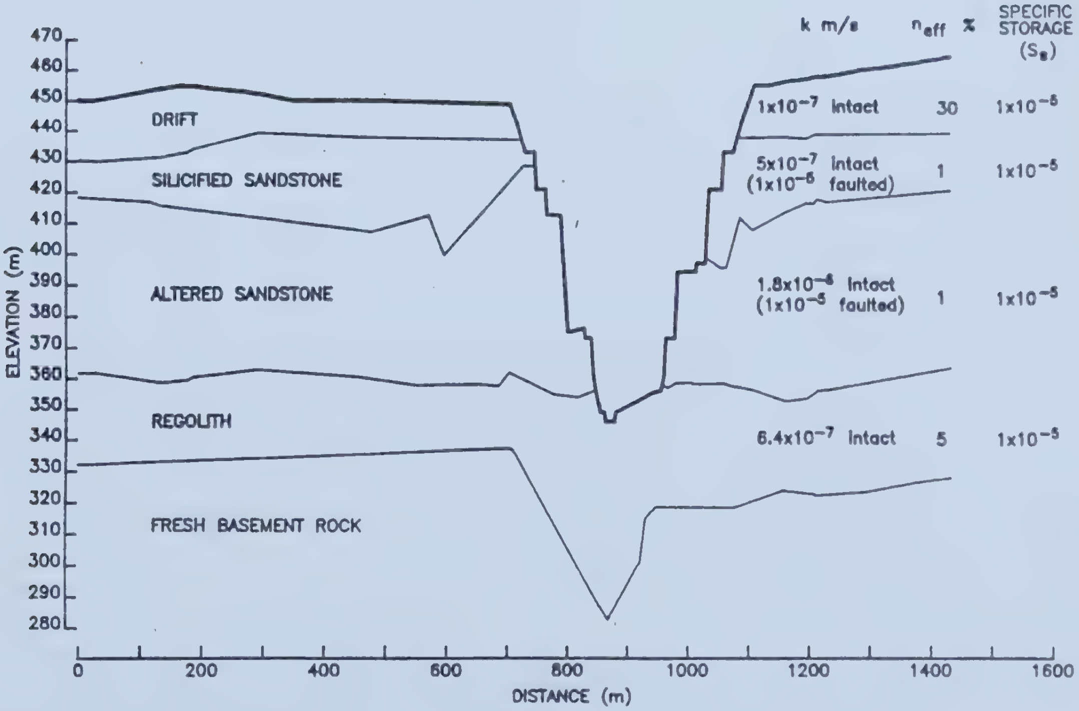
k m/s
n_{eff} %
SPECIFIC STORAGE (S_s)
DRIFT
SILICIFIED SANDSTONE
ALTERED SANDSTONE
REGOLITH
FRESH BASEMENT ROCK
$1x10^{-7}$ Intact
30
$1x10^{-5}$
$5x10^{-7}$ Intact
($1x10^{-6}$ faulted)
1
$1x10^{-5}$
$1.8x10^{-6}$ Intact
($1x10^{-5}$ faulted)
1
$1x10^{-5}$
$6.4x10^{-7}$ Intact
5
$1x10^{-5}$
ELEVATION (m)
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
0
200
400
600
800
1000
1200
1400
1600
DISTANCE (m)

Figure 4 Local Stratigraphy including Material Properties used in the Analysis

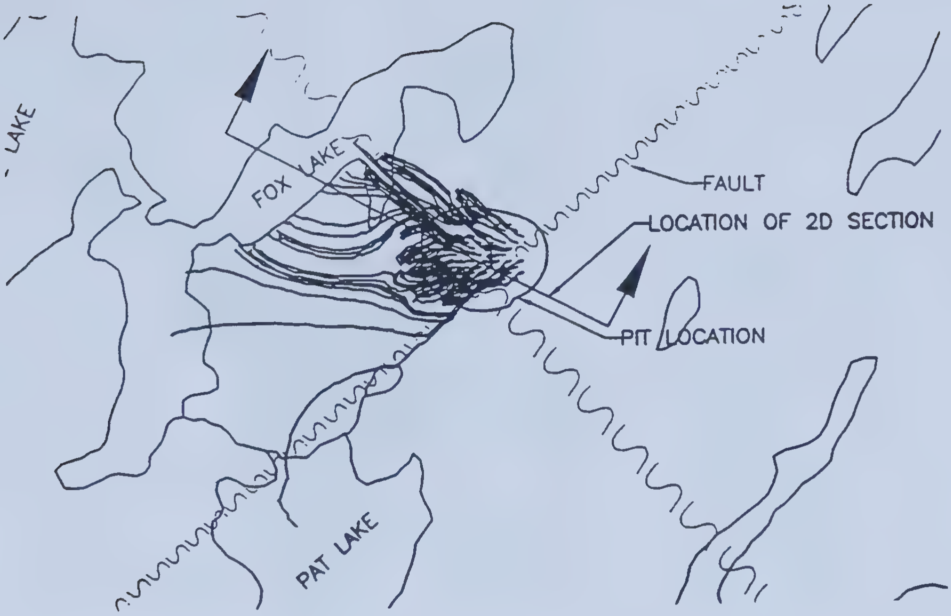
LAKE
FOX LAKE
FAULT
LOCATION OF 2D SECTION
PIT LOCATION
PAT LAKE

Figure 5 Contaminant Transport Pathways

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DECOMMISSIONING AND RECLAMATION OF THE JASPER GOLD MINE IN NORTHERN SASKATCHEWAN

Carl R. Paton and Robert L.J. Phillips
Cameco Corporation
2121 - 11th Street West
Saskatoon, Saskatchewan
S7M 1J3

DECOMMISSIONING AND RECLAMATION OF THE JASPER GOLD MINE IN NORTHERN SASKATCHEWAN

Carl R. Paton and Robert L.J. Phillips

Abstract

The Jasper gold mine operated from February 1990 to June 1991, producing approximately 135,000 tonnes of ore. The ore was hauled off-site for milling and tailings disposal at the nearby Star Lake mill site. In April 1991, a decommissioning and reclamation plan was submitted to the regulatory agencies. The plan was accepted and decommissioning commenced in June and was completed by September 1991. A minimum three year transition phase monitoring programme was then undertaken to monitor the effectiveness of decommissioning work performed and the progress of revegetation.

Decommissioning work performed included sealing access to the underground workings, removing all surface structures and associated facilities, and preparing disturbed areas for revegetation. The mine portal was sealed by backfilling with waste rock. Raise break-throughs to surface were sealed by installing reinforced concrete caps over the openings. The strategy applied for revegetation was the encouragement of natural revegetation while avoiding the permanent introduction of non-native plant species.

The invasion of native plant species on disturbed areas was encouraged by various means. The seeding of short-lived agronomic grasses was successful in stabilizing soil conditions and providing a catchment mechanism for native airborne seeds. Scarification and recontouring of disturbed areas has also proven effective. Slash and deadfall from surrounding areas was also pulled out onto disturbed areas that had not revegetated four years after decommissioning. All of these methods have been effective in encouraging natural revegetation. However, earlier application of the slash and deadfall may have allowed for the abandonment of the property in the third year of the transition phase. The concrete caps used to seal the raise break-throughs to surface have performed as designed. Approval to abandon the site is anticipated in 1996, five years after decommissioning and the start of revegetation.

Introduction

The Jasper mine was a small (300 tonnes per day) underground gold mine located approximately 135 km north of La Ronge, Saskatchewan. The operation produced approximately 135,000 tonnes of ore and 42,500 tonnes of waste while operating from February 1990 to June 1991. Ore was hauled off-site for milling and tailings disposal at the nearby Star Lake mill site.

Decommissioning and reclamation commenced almost immediately upon completion of mining and involved work on minewater settling ponds, mine portal, mine break-throughs to surface, roads, buildings and associated facilities. The decommissioning work done in 1991 was accepted by the agencies and a minimum three-year transition phase monitoring program began. This paper will describe the methods used to decommission the site and the progress of revegetation on disturbed areas.

Decommissioning Plan Development

In order to receive approval for the project an environmental impact statement (EIS) had been submitted in April 1989, as required by the Saskatchewan Environmental Assessment Act. In this EIS, the potential environmental impacts due to mining were assessed and mitigative actions proposed. Areas investigated included acid generation prediction, surface hydrology, hydrogeology, surface water quality, wildlife, fisheries, and heritage resources (*Cameco, 1989*). A conceptual decommissioning and reclamation plan was also included in the EIS.

In April 1991, prior to the end of operating life of the mine, a decommissioning plan was submitted to the agencies. The plan was accepted and decommissioning commenced in June and was completed in September 1991. The transition phase monitoring program was then undertaken to monitor the effectiveness of decommissioning work performed and the progress of revegetation. If the monitoring results of this phase are acceptable to the agencies, an application to be released from the property can be made.

Description of Operations

The Jasper mine was a small underground gold mine accessed by a decline ramp. Mining was completed to a depth of 140 m using a short-hole shrinkage stoping technique. Mine openings to surface consisted of a main access portal, a vent raise, and seven stope raises. Minewater was pumped to surface and into settling ponds before being released to the environment. There were two sets of minewater settling ponds in use at different times to settle out and contain solids. There was no chemical treatment used in these settling ponds. The original set of two ponds were used during the underground exploration phase and were decommissioned soon after full-scale mining started in February 1990. Another set of three settling ponds were commissioned and used throughout the operational life of the mine. The water quality for the effluent discharged to the environment from these settling ponds during operations is shown in Table 1.

Table 1

Minewater Discharge after Settling
Typical Water Quality during Operations

	Feb. - Dec. 1990	Jan. - May 1991
pH	7.13	7.21
Conductivity	414	437
Total Suspended Solids	42	14
Ammonia (un-ionized)	0.09	0.05
Sulphate	43	50
As (total)	0.0012	0.0010
Cu (total)	0.012	0.010
Pb (total)	0.038	0.028
Ni (total)	0.006	0.008
Zn (total)	0.033	0.020

- All units are mg/L except pH (pH units) and conductivity (μS/cm).

No special disposal methods were required for waste rock based on an assessment of their acid-generating potential. Waste rock samples collected during both the exploration and production phases underwent standard acid-base accounting (*Sobek et al., 1978*). The results (Table 2) indicated a very low potential for acid generation given the low sulphur content and high ratio of neutralizing potential to acid production potential. The production waste rock samples also underwent major and trace element whole rock analysis, and a 24-hour agitated leach test (*EPA, 1985*). There were no significant metal levels of concern identified in the waste rock or test leachate. Waste rock was used as construction material for the settling ponds, laydown area, roads, and miscellaneous other uses. Waste rock not used as construction material was stored in a waste rock pile next to the portal.

Table 2

Jasper Waste Rock
Acid-Base Accounting Results

	% Total Sulphur	Acid Potential (AP) (g/kg)	Neutral Potential (NP) (g/kg)	Net Neutral Potential (NNP) (g/kg)	NP/AP
Jasper Waste Rock	0.06 (0.01 - 0.17)	1.9 (0.3 - 5.2)	14.6 (8.4 - 21.3)	12.8 (8.1 - 16.4)	15.9 (4.1 - 27.1)

- Average results are reported with the range shown in brackets.

Decommissioning and Reclamation Methods

Decommissioning and reclamation at Jasper was simplified by the absence of a tailings facility or problems with acid generating waste rock. Decommissioning was limited to the tasks of sealing access to the underground, removing all surface structures and associated facilities, and preparing disturbed areas for revegetation. The primary focus of reclamation at the site was the establishment of self-sustaining vegetation along with the monitoring of decommissioned areas. The strategy applied for revegetation of this site was the encouragement of natural revegetation while avoiding the permanent introduction of non-native plant species.

Natural revegetation was encouraged by various means. In some areas short-lived agronomic species were seeded to stabilize soil conditions and provide a catching mechanism for native airborne seeds. Slash and deadfall from surrounding areas was also pulled out onto disturbed areas. This helped catch seeds and provide shelter for emerging plants. Some areas were recontoured to blend in with the natural topography. The ground was left rough and uneven providing sheltered areas to trap seed and promote germination. Some areas of heavy compaction were scarified to break up the surface and promote revegetation.

Decommissioning of surface facilities and the underground began almost immediately upon completion of mining in May 1991. All surface buildings and associated structures were removed for salvage or disposed of. Some of the unsalvageable material was placed in the underground for disposal and some was placed in a refuse pit at the site. Selected material in the refuse pit was burned as completely as possible. The remaining ash and nonburnable material was then hauled off-site to the Star Lake refuse dump and buried.

All salvageable equipment was removed from the underground workings and the mine allowed to flood naturally. Material left in the underground workings for disposal included wood, steel, plastic, and rubber. The portal entrance was sealed by backfilling with waste rock. Waste rock was backfilled a minimum of 5 metres into the portal entrance. At the portal entrance the waste rock was piled up against the entrance to a minimum depth of 2 metres above the portal's brow. A drainage ditch was established from the portal area to a nearby muskeg. Only minor settling of the backfilled waste rock, at the portal's brow, has been noted during yearly inspections. This area of settling was easily hand-filled with waste rock.

The portal is the only main access to the mine and is located in the side of a steep rock outcrop. All the mine workings are at an elevation below the portal entrance. Therefore, as groundwater flooded the mine, drain-off would be through the portal. Dewatering pumps were shut off in May 1991 and a natural outflow from the portal was observed in November 1991. Water quality monitoring of the seepage from the portal since 1991 is summarized in Table 3.

Table 3

Water Quality of Seepage from Backfilled Jasper Portal

	1991	1992	1993	1994	1995
pH	7.53	7.42	7.42	7.30	7.28
Conductivity	256	325	288	272	269
Total Suspended Solids	9	17	3	24	<1
Ammonia (un-ionized)	0.011	0.020	0.004	0.002	0.001
Sulphate	35	28	20	20	16
As (total)	0.0012	0.0006	0.0008	0.0015	0.0008
Cu (total)	0.021	0.027	0.027	0.030	0.037
Pb (total)	0.135	0.030	0.011	0.018	0.015
Ni (total)	0.009	0.012	0.020	0.006	0.007
Zn (total)	0.097	0.203	0.240	0.143	0.098

- All units are mg/L except pH (pH units) and conductivity (μS/cm)

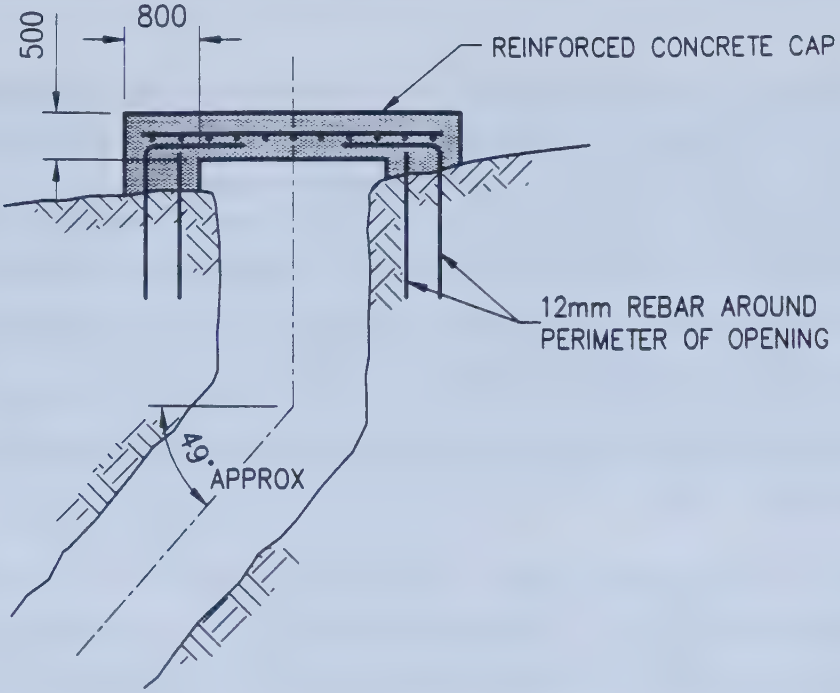
There were a total of seven stope raises that opened to surface and required sealing. These raise break-throughs (B.T.) to surface were approximately 1.8 m × 1.8 m in size and in most cases, the first 2 to 4 m below surface were vertical. Below this the raises sloped at 49° from horizontal (Figure 1). These raises were sealed by installing reinforced concrete caps over the openings. The design of these caps were based on those used to decommission the Beaverlodge site in northern Saskatchewan (*Beaverlodge, 1982*). The caps were constructed by first removing all overburden down to bedrock for a distance of at least 1 metre around the raise B.T. A reinforced concrete cap, a minimum of 0.5 m thick, and extending at least 0.8 m outside the edge of the raise opening was poured over the raise (Figure 1). This cap was anchored to bedrock with a 1/2 inch rebar grouted 1.2 m into solid rock. The spacing between these anchor rebars was no more than 0.6 m and they were installed around the entire perimeter of the opening.

Where the raise openings were on relatively level ground, short footings were used to make a level base for the cap. In cases where the B.T. was on steeply sloping ground, a notch was blasted out around the raise opening to make a level base large enough to accommodate the cap (Figure 2). In all cases the size of the concrete cap was adjusted to ensure they extended at least 0.8 m beyond any fractured ground caused by the raise B.T.

The single vent raise had a 2.5 m × 2.3 m opening which was vertical for the first 4 m below surface, then sloped at 49° from horizontal for the rest of its length. The raise break-through was surrounded by a concrete collar 0.4 m thick, varying in height from 0.2 m to 0.8 m to provide a level base for the mine ventilation fan. The vent raise was sealed in the same manner as the stope raises with a 0.5 m thick reinforced concrete cap anchored to bedrock. This cap enclosed the entire original collar and was anchored to bedrock with rebar all around the outside of this collar.

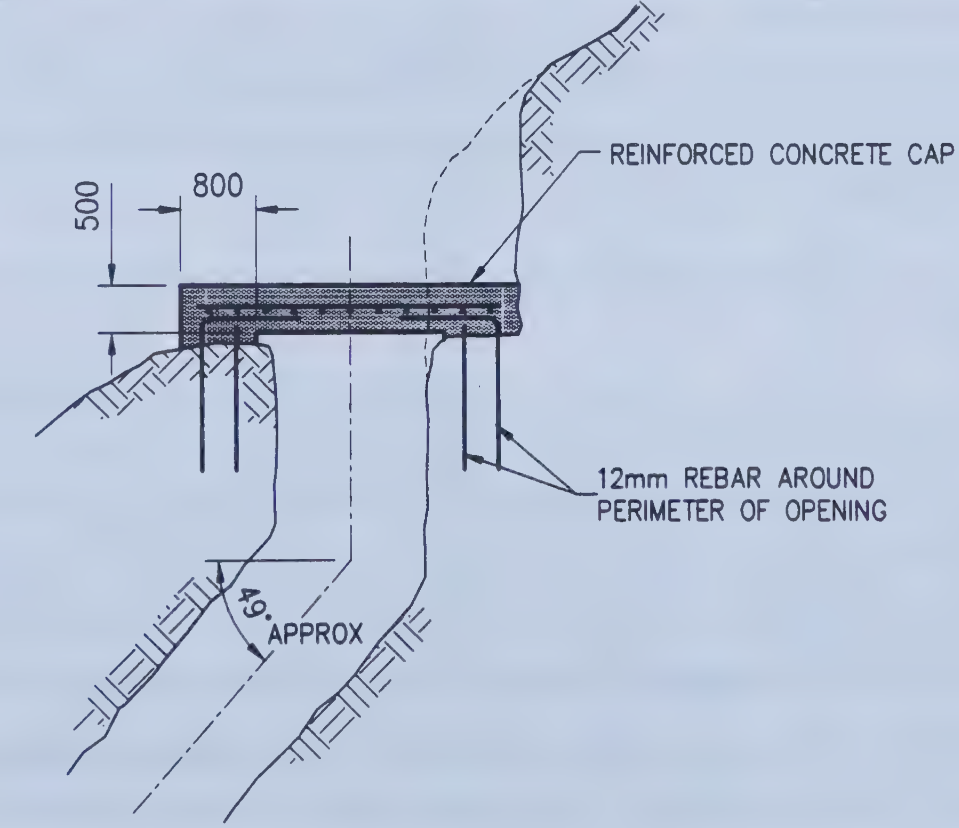
All raise caps have performed as designed based on yearly inspections since their installation in 1991.

The minewater setting ponds were constructed from waste rock and were decommissioned by shutting off the inflow of minewater and allowing the water to drain out. Material from the waste rock pile was used to partially fill in the settling ponds. A bulldozer was then used to push the sides of the waste rock berms into the centre and level out the ponds. In June 1992, the recontoured settling ponds were seeded with a mixture of fall-rye (Secale cereale) and barley (Hordeum vulgare) at a rate of 50 kilograms/hectare (kg/ha). A 16-20-0 (N-P-K) fertilizer was also applied after seeding at a rate of 50 kg/ha. The seed and fertilizer was broadcast using a hand-held seeder. The waste rock pile and portal areas were also seeded at this time. Germination was most successful where the ground was broken and uneven, providing lots of sheltered areas for the seeds. These annual grasses grew well but failed to reach maturity and produce seed due to cold weather in 1992.


500
800
REINFORCED CONCRETE CAP
12mm REBAR AROUND PERIMETER OF OPENING
49° APPROX

TYPICAL RAISE CAP CONSTRUCTION
WITH BREAK-THROUGH ON LEVEL GROUND

FIGURE 1


500
800
REINFORCED CONCRETE CAP
12mm REBAR AROUND PERIMETER OF OPENING
49° APPROX

TYPICAL RAISE CAP CONSTRUCTION
WITH BREAK-THROUGH ON SLOPE

FIGURE 2

JA10C001.DWG
T. ADRIAN
10/03/95

The recontoured settling ponds and other areas seeded in 1992 were re-seeded with the fall-rye and barley mix in May 1993. No fertilizing of these areas was done in 1993. Native plant species had began to invade the disturbed areas by the summer of 1993 and the fall-rye and barley was well established. In 1994 there was no additional effort made to revegetate the minewater settling ponds. Native plant encroachment was progressing and the fall-rye and barley was dying back. By the summer of 1995, native vegetation was well established on the top surface of the recontoured settling ponds. The predominant pioneering species were alder (Alnus sp.), fireweed (Epilobium angustifolium), and a variety of grasses. However, there was still only limited revegetation of the side slopes at the margins of the settling ponds. These side slopes are generally short (1-4 m) and composed of coarse-sized waste rock. The regulatory agencies required that additional work be done to accelerate the revegetation of these side slopes. Therefore in September 1995, brush and deadfall was pulled from the surrounding area and placed on the side slopes. This method has been successful in enhancing natural revegetation at other Cameco operations. The regulatory agencies have indicated that this additional work will fulfil their revegetation requirements.

A portion of the waste rock pile was removed for use in sealing the portal and decommissioning the settling ponds. The remaining pile was contoured to match the local topography and had a slope of approximately 26°. The recontoured pile was seeded with the fall-rye and barley mix in 1992 and 1993. Three years after the initial seeding, the fall-rye and barley has died back and there is patchy coverage by native species.

Some sections of the main access road were scarified in 1991. After three years native grasses have invaded most of these areas and are concentrated in the furrows left by scarification. Sections that were not scarified showed varying degrees of revegetation. In the fall of 1995, slash and deadfall was placed on the sections that remained bare. This debris would serve as a seed trap and also discourage people from driving on these decommissioned roads. The continued presence of vehicular traffic on the main mine access road had a noted effect on revegetation. This was the case even with the very light traffic experienced. Distinctive bare areas were noted in the tire tracks along the main access road with vegetation growing on the untravelled centreline. This effect was further demonstrated by the progress of natural revegetation observed on some of the secondary mine roads that had not been travelled on since decommissioned in 1991. By 1995, some of these roads were completely overgrown by alder, some reaching 1 m in height. Another likely factor is the limited size of these disturbances and subsequently their close proximity to undisturbed areas which act as a seed source. This is supported by observations at this site of better revegetation on the smaller isolated areas.

Saskatchewan Government/Cameco Interaction

When Cameco decided decommissioning of the site was to proceed, Saskatchewan Environment and Resource Management, Industrial Branch (SERM-IB) was contacted. A decommissioning plan was developed using the conceptual plan in the EIS as a guide and submitted to SERM-IB for approval. The proposed plan was circulated to other provincial departments for comment. Approval to decommission was received after accommodating concerns raised by the agencies.

During the decommissioning of the site, SERM-IB made monthly inspections and at times more frequent depending on the decommissioning in progress. From these inspections recommendations and direction were given so that compliance with the plan and regulations could be maintained as decommissioning progressed.

During the transition phase, the period following decommissioning, annual inspections by SERM and the branches who had a stake in the approvals, were conducted. From these inspections, additional direction was supplied which would allow, by the end of the transition phase, the site to be returned to the province. The minimum transition phase period, as established in the approvals, was three years. We are now entering the fifth year. It is anticipated approval to abandon will be given in 1996.

The reason approval was not given after three years was that sufficient natural self-sustaining vegetation had not developed.

The other department that issued approvals to decommission the surface openings was the Occupational Health and Safety Division, Mines Branch. They were also part of the initial annual inspections during the decommissioning and transition phases.

Annual fees paid to the province during the decommissioning and transition phases were the surface lease and local tax payments. To minimize surface lease payments, the undeveloped/developed portions of land were reassessed during the decommissioning phase and an application made to reduce the undeveloped and developed portion of the lease. During the transition phase it was negotiated to eliminate the entire developed portion, therefore, paying undeveloped rates.

Local taxes were reduced by requesting annual reassessment as buildings were removed.

Conclusions

Decommissioning of the Jasper mine was accomplished in four months. The removal of all surface buildings and associated structures left the site ready for revegetating. Backfilling the portal with waste rock has proven to be an effective method of sealing the underground, when a watertight seal is not required. The design and installation of the concrete caps has also proven to be effective in sealing raise break-throughs to surface.

Natural revegetation of disturbed areas at this site has occurred to varying degrees in the four years since decommissioning. Various methods have proven effective in enhancing the progress of natural revegetation. The planting of short-lived agronomic grasses (fall-rye and barley) was successful in catching airborne seeds thereby establishing native vegetation. These short-lived grasses had died back after three to four years, avoiding the permanent introduction of non-native species.

Scarification of disturbed areas was found to be effective in promoting revegetation, especially on areas that experienced heavy soil compaction, such as mine roads. Slash and deadfall from undisturbed areas was useful for trapping native airborne seeds and discouraging traffic on disturbed areas. After four years, the progress of natural revegetation was as expected. Earlier application of the slash and deadfall may have allowed for the abandonment of the property in the third year of the transition phase. The various methods used to encourage natural revegetation were successful. Approval to abandon the site is anticipated in 1996. A final inspection will be done in late summer to determine if there are any outstanding issues.

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Beaverlodge 1982. *Decommissioning of the Beaverlodge Mine/Mill Operations and Reclamation of the site - Closure of Surface Openings.* Eldorado Nuclear Limited. August 1982.

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ENVIRONMENTAL MANAGEMENT FOR MINING
1995 SASKATCHEWAN CONFERENCE

PRACTICAL ASSESSMENT OF BRINE MIGRATION FROM A POTASH TAILINGS MANAGEMENT AREA

By:

Phil Bruch, M.Sc., P.Eng., AGRA Earth & Environmental Limited, 3017 Faithfull Avenue, Saskatoon, Saskatchewan, S7K 8B3
Lyle Kajner, M.Sc., P.Eng., VEMAX Management Ltd., 209-15 Innovation Blvd., Saskatoon, Saskatchewan, S7N 2X8

PRACTICAL ASSESSMENT OF BRINE MIGRATION FROM A POTASH TAILINGS MANAGEMENT AREA

By:
Phil Bruch, M.Sc., P.Eng.
Lyle Kajner, M.Sc., P.Eng.

ABSTRACT

Numerical modelling is a powerful tool that has become common in engineering use in recent years. With advancements in hardware and software, complex models can be developed to simulate numerous problems related to the mining industry, including seepage flows, solute transport, and deformations. Numerical modelling is often required for the planning, operation and decommissioning of minesites. However, even though the models used will provide solutions with high precision, it is important to recognize that the systems being modelled are probabilistic. The inputs to the model can not be established with certainty. This uncertainty in the inputs generates uncertainty in the model outputs, regardless of how sophisticated the numerical model is. In many cases, a probabilistic treatment of the problem, using a less sophisticated numerical model, yields cost effective, timely and insightful results.

As an example, a probabilistic methodology was used to quantify the potential for off-site brine migration from the tailings management facility of a potash mine. Conventional practice would have utilized a deterministic analysis with a (complex) seepage/solute transport model; however, after investigating the problem further, a simple (1-dimensional) solute transport model was adopted and implemented within a discrete probabilistic simulation framework. This methodology permitted the estimation of the potential for off-site brine migration.

The methodology is outlined in the paper within the context of a specific application conducted at the Agrium Inc. potash mine located near Vanscoy, Saskatchewan. It is simple and applicable to many problems requiring numerical simulation in mining and mine decommissioning.

1.0 INTRODUCTION

Numerical modelling is a powerful tool that has become common in engineering use in recent years. With advancements in hardware and software, complex models can be developed to simulate numerous problems related to the mining industry, including seepage flows, solute transport and deformations. Numerical modelling is often required for the planning, operation and decommissioning of minesites. However, even though the models used will provide solutions with high precision, it is important to recognize that the physical systems being modelled are probabilistic. The values of the model inputs can not be established with certainty. This uncertainty in the inputs generates uncertainty in the model outputs, regardless of how sophisticated the numerical model is. In many cases, a probabilistic treatment of the problem, using a less sophisticated model, yields cost effective, timely and insightful results.

This paper presents a summary of a case history of the use of discrete probabilistic simulation to investigate the potential for off-site brine migration from the Agrium Inc. (formerly Cominco Fertilizers) potash mine near Vanscoy, Saskatchewan. The study was conducted by AGRA Earth & Environmental Limited (AEE, formerly HBT AGRA Limited) in 1992-1993.

2.0 BACKGROUND

The Tailings Management Facility (TMF) at the Agrium Inc. Potash Mine near Vanscoy, Saskatchewan occupies approximately 370 ha in Twp. 35, Rge. 8, W3M. The layout of the TMF is shown on Figure 1. The current operation of the TMF involves hydraulically discharging the combined salt tailings and insols ("slimes") waste streams from the mill on top of the salt pile and successively decanting the fluid through a series of ponds, polishing the brine effluent to obtain a clarified brine solution which is collected in the North Brine Pond.

The TMF is located in a shallow, local, northwest trending valley. The trough of the valley is generally oriented along the longitudinal axis of the TMF with the ground surface sloping towards the TMF on the west, south and east sides. The ground slopes away from the TMF on the north side of the TMF towards Rice Lake. The surficial soils in the area under consideration consist of an interbedded sand and silty sand unit which coarsens upward. The distribution of sand beds within this unit is chaotic and unpredictable, although individual sand beds may have considerable longitudinal continuity (Eyles et al, 1984). This surficial soil unit is underlain by a silty clay and clay unit which acts as an aquitard.

The purpose of this study was to examine the potential for off-site brine migration from the Northeast portion of Agrium's TMF towards NE22-35-8-W3M. The location of interest is shown as Section A-A on Figure 1. This location represents the shortest seepage path for off-site brine migration in the area under consideration. Brine migration from the TMF is known to be occurring in this area and is currently being monitored using a series of monitor wells and surface electromagnetic (EM) surveys. The scope of this study included a geotechnical investigation consisting of seventeen test holes and piezometers, field and laboratory hydraulic conductivity testing and engineering analysis.

In conducting this study, AEE intentionally imposed several limitations on the field program and on the subsequent engineering analysis in order to focus the study on the relevant issues and to facilitate the completion of the project within time and budgetary constraints. The scope of this study was defined as follows:

- The study area was defined as Section 15 and the northern half of Section 22 - Twp.35, Rge.8, W3M.
- The study was conducted for time frames of 25, 50 and 75 years assuming T=0 on January, 1, 1993.
- The progression of the brine front away from the TMF was modelled assuming its initial location was as defined by the EM survey work completed by the Saskatchewan Research Council (Maathuis, Jaworski and Zlipko, (1993)).
- The estimate of the likely extent of brine migration assumed that the operation of the TMF, and the corresponding flow regime around the TMF, remained essentially consistent with that established in December 1992 (i.e., steady state flow conditions).
- It was assumed that the pre-mine development flow regime would be re-established after the mine was decommissioned. This would result in groundwater flow back toward the TMF, reducing further brine migration toward the northeast.
- The development of finite difference or finite element computer models were considered to be "out of scope" for this study.
- Density dependent flow was modelled implicitly rather than explicitly.
- Discrete probabilistic simulation was used to quantify the uncertainty associated with the soil parameters and flow characteristics.

The level of effort required to develop a regional finite difference or finite element computer model capable of explicitly modelling density dependent flow would be far in excess of the budget allocated to this study. AEE specifically selected a probabilistic analysis framework to quantify shortcomings in the analysis resulting from either the simplistic nature of the solute transport model or the uncertainty associated with the soil parameter and flow characteristic estimates. If this preliminary assessment indicated a significant potential for off-site brine migration, a more complex analysis would have been implemented. Staging the analysis in this fashion was considered to be an efficient allocation of resources.

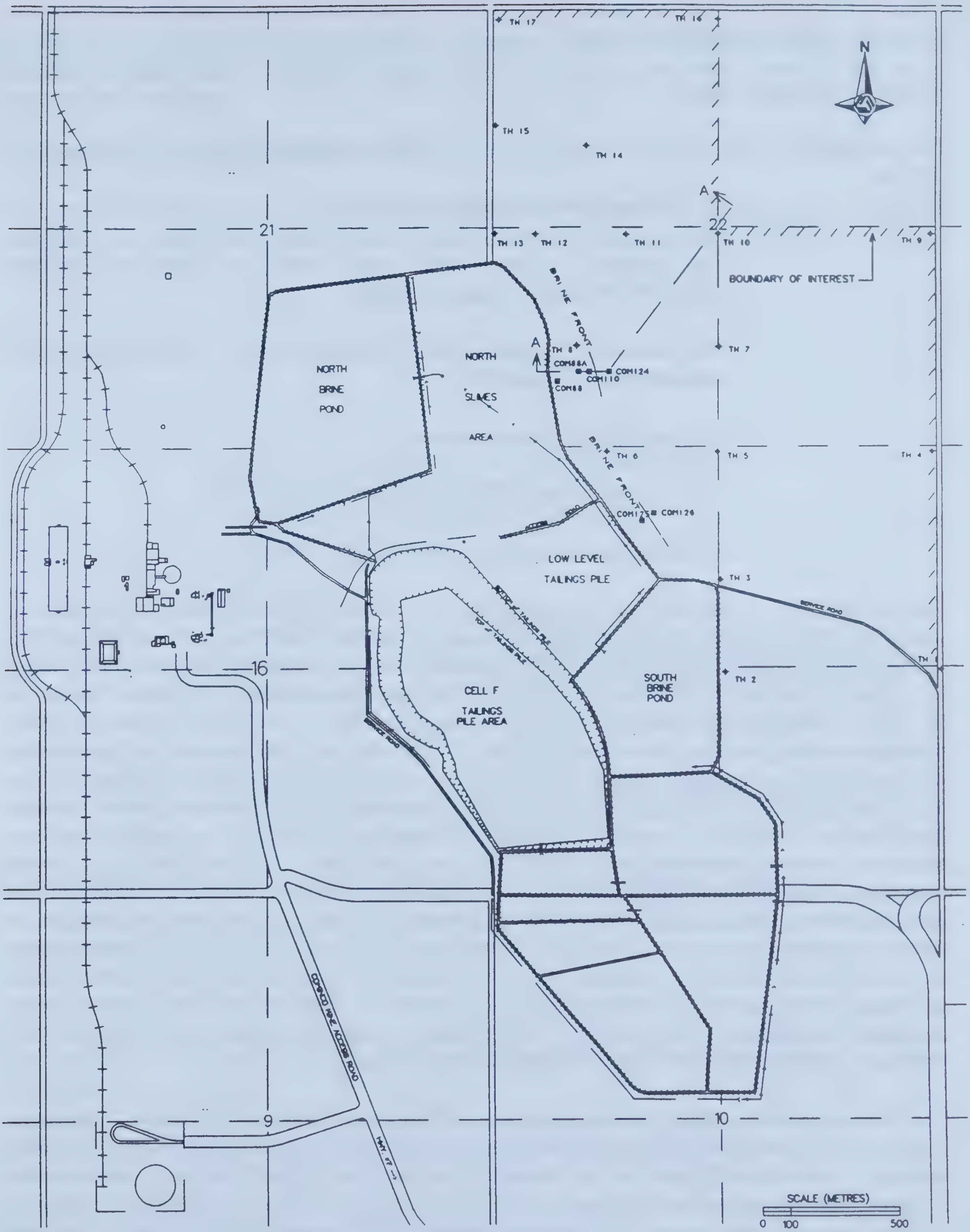
N
TH 17
TH 16
TH 15
TH 14
A
21
22
TH 13
TH 12
TH 11
TH 10
TH 9
BOUNDARY OF INTEREST
NORTH BRINE POND
NORTH SLIMES AREA
BRINE FRONT
A
TH 8
COM88A
COM124
COM110
COM88
TH 7
TH 6
TH 5
TH 4
COM125
COM126
ACCESS ROAD
LOW LEVEL TAILINGS PILE
TH 3
SERVICE ROAD
BOTTOM OF TAILINGS PILE
TOP OF TAILINGS PILE
TH
16
TH 2
SOUTH BRINE POND
CELL F TAILINGS PILE AREA
SERVICE ROAD
COMINCO MINE ACCESS ROAD
HWY. 97 →
9
10
SCALE (METRES)
0
100
500

Figure 1 Site Plan

3.0 ANALYSIS METHODOLOGY

3.1 Solute Migration Model

The assumptions made for the analysis of the rate of brine migration from the TMF were as follows:

- The flow was one-dimensional (horizontal).
- The advance of the brine front could be described by the Advection-Dispersion Equation (ADE).
- The solute of concern (salt) was non-reactive, non-decaying, and conservative (no retardation).
- Only saturated flow was considered.
- The flow system was uniform and at steady state.
- The soils were homogeneous and isotropic

The assumption of one-dimensional flow has a slight error associated with it due to the existence of density dependant flow; however, as discussed above, the explicit modelling of density driven flow was beyond the scope of this project. Density dependent flow was implicitly modelled by adjusting the gradient in an attempt to simulate the higher driving head associated with the brine. The use of the ADE to calculate the movement of the brine front enabled the use of closed-form analytical solutions, resulting in rapid, yet accurate solutions. As a solute, salt is non-decaying and is generally non-reactive and non-retarded. However, this assumption neglects the possibility that precipitation of salt may occur. The assumption of saturated flow is reasonable, given that the aquifer in question is surficial and unconfined. As well, determination of unsaturated hydraulic conductivity functions and solute transport parameters was beyond the scope of this study. The assumption of a steady state flow system is a reasonable approximation given the scope of this study. It was recognized that the materials in the aquifer were not homogeneous and isotropic; however, the variation in material properties was accounted for in the probabilistic ranges assigned to the input variables used in the discrete probabilistic analysis. The brine migration from the TMF is currently being monitored using surface electromagnetic (EM) surveys. These surveys will assist in the calibration/verification of the modelling. If significant heterogeneity exists, the EM surveys will detect an increased rate of lateral brine migration in those areas.

The flow components of the ADE are advection, diffusion and mechanical dispersion. Advective transport is the process by which the solute is transported at the rate of the interstitial groundwater velocity. Molecular diffusion is the decrease in solute concentration due to a concentration gradient, and due to the thermal kinetic energy of the particles (Brownian motion). Molecular diffusion can (and does) occur in the absence of advection. Theoretically, diffusion will continue until the concentration gradient is equal to zero. Mechanical dispersion refers to the nonsteady irreversible mixing of two miscible fluids displacing one another in a porous medium. Mechanical dispersion occurs due to microscopic velocity variations within the porous medium. Details regarding the basic theory of solute migration can be found in Freeze and Cherry (1979) and numerous other textbooks.

3.2 Advection Dispersion Equation (ADE)

The one-dimensional form of the advection-dispersion equation of nonreactive dissolved constituents in saturated, homogeneous, isotropic materials under steady state, uniform flow is as follows:

$$D \frac{\partial^2 C}{\partial l^2} - v \frac{\partial C}{\partial l} = \frac{\partial C}{\partial t}$$

where:

l = curvilinear coordinate direction taken along the flow line
v = the average interstitial groundwater velocity
D = the coefficient of hydrodynamic dispersion
C = the solute concentration
t = time
and v = $ki_{ADJ,}/n$
where k = hydraulic conductivity
i_{ADJ} = hydraulic gradient (adjusted to account for density differences between brine and fresh water).
n = porosity
D = (D* + αv)
where D* = apparent coefficient of mechanical dispersion
α = dispersivity

For a step function input, the boundary conditions are represented mathematically as:

$C(l,0) = 0 \qquad l \geq 0$
$C(0,t) = C_o \qquad t \geq 0$
$C(\infty,t) = 0 \qquad t \geq 0$

The solution to the one-dimensional ADE for the above boundary conditions is given by Ogata (1970) as:

$$\frac{C}{C_o} = \frac{1}{2}\left[erfc\left(\frac{l - vt}{2\sqrt{Dt}}\right) + \exp\left(\frac{vl}{D}\right) erfc\left(\frac{l + vt}{2\sqrt{Dt}}\right)\right]$$

where: erfc = the complementary error function
C_o = initial concentration
C, l, v, t, D = same as previously defined

A computer program was used to solve the equation given by Ogata (1970) for the concentration ratio (C/C_o) at various distances and times. A concentration ratio of 0.001 was used to define the extent of the solute plume. A discrete probabilistic simulation was used to account for variations in the input parameters (k, i_{ADJ}, D^* and α). The discrete probabilistic simulation is described in the following sections.

3.3 Probabilistic Framework

In order to quantify the uncertainty associated with our estimate of travel distances for the brine front, the ADE solute transport model was implemented with in probabilistic framework. This framework is shown in Figure 2. Note that we have chosen the terminology "framework" rather than model, because a specific software tool was not need to facilitate this particular example. However, it should be recognized that commercial "probabilistic simulation" software tools do exist, and they may be useful in other applications. For this application, the processing of the probabilistic information (the input/output from the ADE model) was using a spreadsheet.

A discrete probabilistic framework for this analysis was selected to quantify the uncertainty surrounding the input parameters for the one-dimensional ADE solute transport model. Discrete probabilistic simulation was selected over continuous probabilistic simulation as it is more efficient for problems with a limited number of state variables.

Discrete probabilistic simulation uses discrete approximations to represent the probability distributions which describe the uncertainty associated with each of the probabilistic state variables. The probabilistic state variables are simply the random variables in the numerical model being simulated that are to receive probabilistic consideration (in this example: k_h, i_{ADJ}, D^* and α). The set of probabilistic state variables and their discrete approximations define a series of possible scenarios (number of scenarios=z) for the simulation. Each scenario has a unique outcome ($d(x)_z$) and a unique probability of occurrence ($p(x)_z$). The probabilistic outcome set ($d(x)_z$, $p(x)_z$ for all (z) can be ranked by outcome and compiled into frequency or cumulative probability distributions. The total number of model runs (z) required to solve a discrete probabilistic simulation is a finite number known to the analyst prior to running the simulation. The degree of discretizing the probability distributions for each probabilistic variable can be manipulated to adjust the total number of model runs required to solve the simulation. For this study, four probabilistic state variables were modelled using a 3 branch approximation for each.

Graphically, the scenarios developed for the simulation of the ADE one-dimensional solute transport can be expressed using the decision tree shown in Figure 3. Each path through the decision tree represents one possible scenario. Multiplying the probabilities along a path through the tree gives the probability of that particular scenario occurring. The simulation is completed by calculating the outcome and associated probability for every path through the tree. For this application there were 81 possible paths through the tree; therefore, for each time step (25, 50, 75 years) the ADE model would be iterated 81 times.

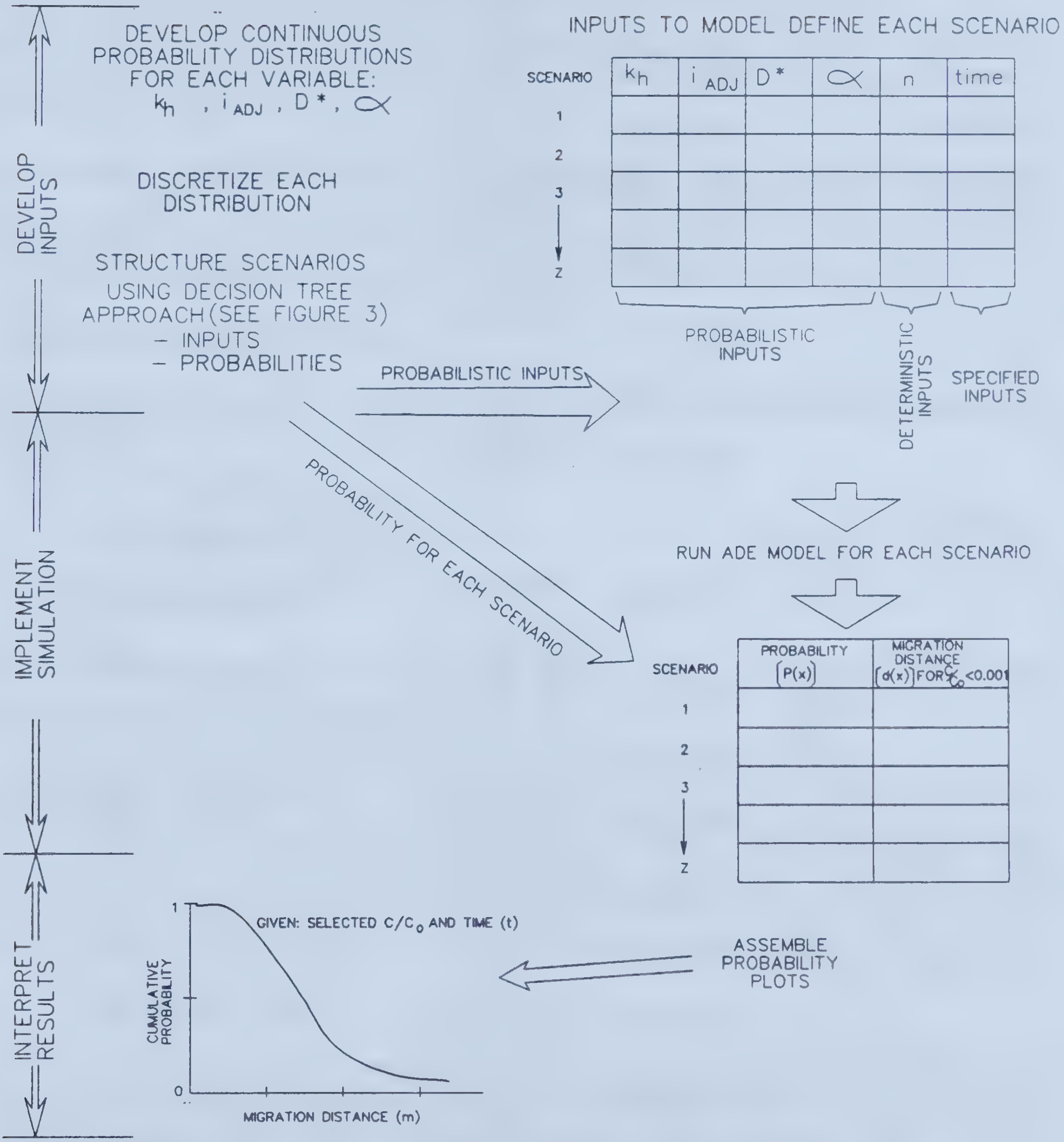
DEVELOP INPUTS
DEVELOP CONTINUOUS PROBABILITY DISTRIBUTIONS FOR EACH VARIABLE:
k_h, i_{ADJ}, D^*, α
DISCRETIZE EACH DISTRIBUTION
STRUCTURE SCENARIOS USING DECISION TREE APPROACH (SEE FIGURE 3)
- INPUTS
- PROBABILITIES
INPUTS TO MODEL DEFINE EACH SCENARIO
SCENARIO
k_h
i_{ADJ}
D^*
α
n
time
1
2
3
Z
PROBABILISTIC INPUTS
DETERMINISTIC INPUTS
SPECIFIED INPUTS
PROBABILISTIC INPUTS
IMPLEMENT SIMULATION
PROBABILITY FOR EACH SCENARIO
RUN ADE MODEL FOR EACH SCENARIO
SCENARIO
PROBABILITY $[P(x)]$
MIGRATION DISTANCE $[d(x)]$ FOR C/C_o <0.001
1
2
3
Z
INTERPRET RESULTS
ASSEMBLE PROBABILITY PLOTS
1
0
CUMULATIVE PROBABILITY
GIVEN: SELECTED C/C_0 AND TIME (t)
MIGRATION DISTANCE (m)

Figure 2 Probabilistic Framework

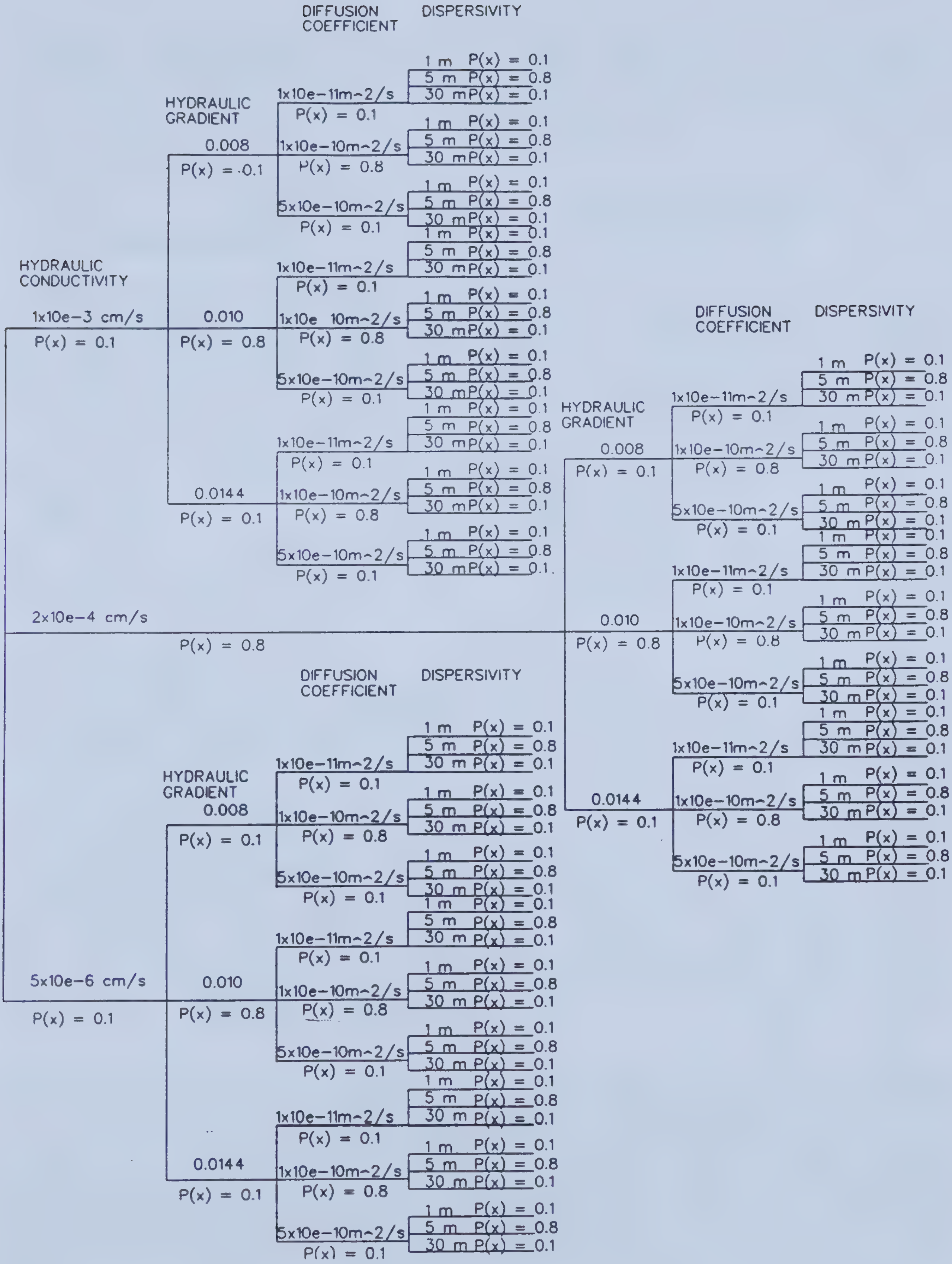
DIFFUSION COEFFICIENT
DISPERSIVITY
HYDRAULIC GRADIENT
HYDRAULIC CONDUCTIVITY
1x10e-3 cm/s
P(x) = 0.1
0.008
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.010
P(x) = 0.8
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e 10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.0144
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
2x10e-4 cm/s
P(x) = 0.8
HYDRAULIC GRADIENT
DIFFUSION COEFFICIENT
DISPERSIVITY
0.008
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.010
P(x) = 0.8
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.0144
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
DIFFUSION COEFFICIENT
DISPERSIVITY
HYDRAULIC GRADIENT
5x10e-6 cm/s
P(x) = 0.1
0.008
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.010
P(x) = 0.8
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
0.0144
P(x) = 0.1
1x10e-11m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
1x10e-10m~2/s
P(x) = 0.8
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1
5x10e-10m~2/s
P(x) = 0.1
1 m P(x) = 0.1
5 m P(x) = 0.8
30 m P(x) = 0.1

Figure 3 Decision Tree

Developing the discrete approximation for each probabilistic state variable is a two step process. First, a continuous probability function for each variable must be developed. This can be accomplished by using historical observations and generating probabilistic estimates based on relative frequency, or by encoding subjective probabilistic information. Techniques for developing probabilities based on relative frequency and subjective information are described in Kajner (1990), Gregory (1988), Bunn (1984), Holloway (1979) and Kahneman and Tversky (1974). When encoding subjective probabilities care must be exercised to avoid common heuristics and biases that may occur (Kahneman and Tversky (1974)).

Once the cumulative probability distribution is developed for each variable, it is discretized to form a discrete approximation of the cumulative distribution. This process involves creating a step function along the cumulative probability curve that balances the individual areas above and below the line. This process can be done by eye or by using calculus (Celona and McNamee (1987)).

3.3.1 Developing Probabilistic Inputs

The probabilistic variables in the ADE model were assumed to be probabilistically independent. The following four variables were modelled probabilistically:

- hydraulic conductivity, k_h
- hydraulic gradient, i_{ADJ}
- diffusion coefficient, D^*
- dispersivity, α

The porosity (n) of the soil was modelled as a deterministic input because the uncertainty associated with the estimate of n was felt to be relatively small.

The following sections provide an explanation of the rationale used in selecting the discrete probabilistic approximations for each probabilistic state variable used in the simulation. The initial step of developing a cumulative distribution for each probabilistic state variable has not been included in this paper, but is available in Kajner, Bruch and Muir (1993). For the purpose of this study, both relative frequency and subjective information were utilized in developing the probabilistic inputs for the ADE model.

3.3.1.1 Hydraulic Conductivity, k

The advective-dispersion model described previously requires an estimate of the bulk saturated horizontal hydraulic conductivity of the aquifer (k_h). This requires that the assumption is made that the soils in the aquifer are homogeneous. The actual horizontal hydraulic conductivity of the surficial aquifer will in fact vary with location and depth as a result of the varying stratigraphy of the site and the degree of disturbance of the sediments (zones of weathering, influence of vegetation, fractures, etc.). The post glacial, Lake Saskatchewan Sediments that comprise the surficial aquifer vary from an oxidized silty sand to an oxidized silty clay with a majority of the flow within the aquifer expected to occur through the oxidized silty sand zone.

In order to develop an estimate of k_h the following information sources were reviewed:

- slug tests, (part of the field program)
- triaxial hydraulic conductivity tests: Kajner and Muir (1993)
- back-calculation from EM surveys, Maathuis and van der Kamp (1983)
- published typical values, Freeze and Cherry (1979) and Holtz and Kovacs (1981)

The hydraulic conductivity estimates from the various sources are summarized in Table 1. From Table 1 it is evident that k_h of this particular soil unit may vary within a wide range of 10^{-2} cm/s to 10^{-7} cm/s. Considering that: 1) that the soils are comprised of predominantly finer grained material with typically over 80 % passing the #200 sieve, 2) the fines are low to medium plastic, 3) allowing for influence of weathering and possible fractures, and 4) allowing for the heterogeneity of the aquifer soils, the following discrete probabilistic estimate was developed for the bulk horizontal hydraulic conductivity of the aquifer:

- $k_h=1x10^{-3}$ cm/s with a probability of 0.1
- $k_h=2x10^{-4}$ cm/s with a probability of 0.8
- $k_h=1x10^{-6}$ cm/s with a probability of 0.1

Table 1 Summary of Hydraulic Conductivity Values Used to Develop Discrete Probabilistic Estimate

Material	Hydraulic Conductivity (cm/s)	Reference
Silt (Test Hole 4)	2.3×10^{-4}	Kajner, Bruch and Muir, 1993
Silt (Test Hole 7)	2.2×10^{-4}	Kajner, Bruch and Muir, 1993
Silty Clay (Test Hole 14)	9.6×10^{-6}	Kajner, Bruch and Muir, 1993
Silt (Test Hole Com 124)	1.7×10^{-4}	Kajner, Bruch and Muir, 1993
Silty Sand (Triaxial)	4.1×10^{-6}	Kajner and Muir, 1993
Medium Plastic Clay (triaxial)	1.4×10^{-7}	Kajner and Muir, 1993
Silty Sand	10^{-1} to 10^{-5}	Freeze and Cherry, 1979
Silt	10^{-3} to 10^{-7}	Freeze and Cherry, 1979
Fine Sands, Silts, Mixtures of Sand Silts and Clays, Stratified Clays	10^{-3} to 10^{-7}	Holtz and Kovacs, 1981
Impervious Soils Modified by Weathering	10^{-2} to 10^{-7}	Holtz and Kovacs, 1981
Surficial Sediments	1.7×10^{-4}	Back calculation from EM surveys by Maathuis and van der Kamp, 1983

3.3.1.2 Hydraulic Gradient, i_{ADJ}

The estimate of the hydraulic gradient (i_{ADJ}) used in the analysis is the sum of two components: 1) the estimated linear slope of the phreatic surface and 2) an estimated correction factor to implicitly consider the variations in fluid density. The estimate is an average value over the entire length of the flow path being analyzed. The flow regime responsible for transporting the brine is influenced by the density of the fluid being modelled. Because the ADE model does not "explicitly" consider density dependent flow, density effects were "implicitly" considered by converting the measured fluid head to a freshwater equivalent head. This conversion simulates a higher driving head for the denser brine fluid[1]. The derivation of the estimates for the two components of i_{ADJ} is described in detail below.

The analysis conducted in this study predicts the advancement of the brine front from its known location in 1992 (defined as point d_0). As such, much of the uncertainty associated with predicting the hydraulic gradient is reduced because the influence of the TMF on the hydraulic gradient is less pronounced beyond this location. The development of the estimates for hydraulic gradient northeast of this starting position (point d_0) considered the following factors:

- the regional groundwater flow regime and its seasonal patterns;

  Maathuis, Jaworski and Zlipko (1993) documented seasonal groundwater fluctuations in the surficial aquifer in the order 1 to 2 m. The highest groundwater levels were documented in May-July after spring recharge and the lowest levels in February-March just prior to spring recharge. Secondary recharge events were occasionally evident after major precipitation events.

  The impact of variations in the regional groundwater regime on the conclusions of this analysis will be muted by the fact that the hydraulic gradient is relative. Because Sections 15 and 22 are removed from any natural groundwater boundaries (i.e. lakes, river, groundwater divides, etc.) if the regional groundwater table is drawn down, it will be drawn down throughout the study area and the gradient will not significantly change over the flowpath being analyzed.

- the fluid level in the TMF;

  The fluid levels in the south brine pond, north brine pond and connecting ditches effect the degree of mounding of the water table (and rate of brine escape); however, its influence will be constrained by the configuration of the ditch system along the toe of the east dyke. The aquifer is considered to be unconfined and as such the (fluid) head at the ditch can not exceed the fluid level in the ditch (although an allowance for density must be added). It is therefore reasonable to assume that if Agrium continues to maintain the current ditch system, the mounding of groundwater table as a result of the brine levels in the TMF should not significantly exceed those measured in December 1992.

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[1] Specific gravity of brine (@ 15.5°C) = 1.230

Fluid levels in the retention pond area will have a local effect on the groundwater table; however, this area is a discharge zone for the flow path being analyzed and consequently its impact on the "averaged" gradient will be minimal.

- density effects;

  The estimate of the hydraulic gradient has been adjusted to reflect the increased density of the brine by increasing the hydraulic gradient by a constant. The estimate of the constant was developed by assuming that the dispersion of the brine front occurred over an average distance of 200 m. The specific gravity of the fluid was assumed to increase linearly from 1.000 at the leading edge of the brine front to 1.230 at a distance 200 m into the solute plume. The average thickness of fluid in the aquifer over the flow path being analyzed was assumed to be 4 m. Given the assumption made above, the slope of the "density" gradient was calculated to be 0.0046. This method of approximating the density effect will contribute to a pessimistic approximation of the advancement of the brine front as it applies the gradient correction over the entire flow path and not just at the advancing front of the solute plume.

All three scenarios assume the existing fluid level at d_o remains constant (as controlled by the levels in the TMF and ditch system). The average gradient scenario approximates the flow regime measured in December 1992. The following discrete probabilistic estimate was developed for the adjusted hydraulic gradient, as illustrated in Figure 4:

- $i_{ADJ} = 0.014$ with a probability of 0.1
- $i_{ADJ} = 0.010$ with a probability of 0.8
- $i_{ADJ} = 0.008$ with a probability of 0.1

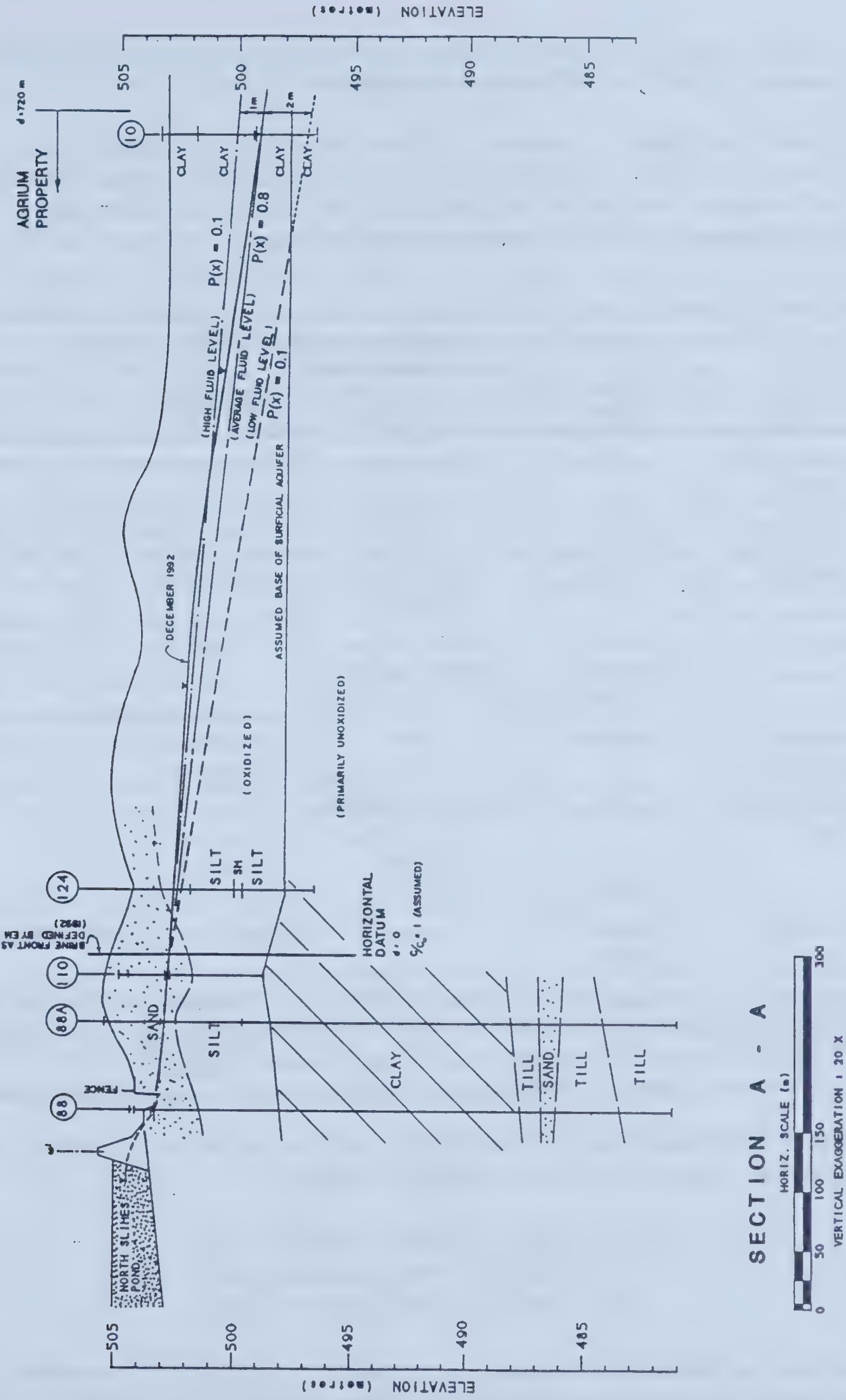
AGRIUM PROPERTY
d=720 m
10
124
110
88A
88
BRINE FRONT AS DEFINED BY EM SURVEYS (1992)
FENCE
NORTH SLIMES POND
CLAY
SAND
SILT
SH
TILL
(HIGH FLUID LEVEL) P(x) = 0.1
(AVERAGE FLUID LEVEL) P(x) = 0.8
(LOW FLUID LEVEL) P(x) = 0.1
1m
2m
DECEMBER 1992
ASSUMED BASE OF SURFICIAL AQUIFER
(OXIDIZED)
(PRIMARILY UNOXIDIZED)
HORIZONTAL DATUM d = 0
%c = 1 (ASSUMED)
ELEVATION (metres)
505
500
495
490
485
SECTION A - A
HORIZ. SCALE (m)
0
50
100
150
300
VERTICAL EXAGGERATION : 20 X

Figure 4 Illustration of Hydraulic Gradient Scenarios

3.3.1.3 Apparent Coefficient of Molecular Diffusion, D*

The apparent coefficient of molecular diffusion varies over a relatively small range, from approximately 10^{-10} to 10^{-11} m^2/s (Freeze and Cherry, 1979). Further, it must be less than or equal to the diffusion coefficient for free solution (2×10^{-9} m^2/s). A summary of apparent coefficients of molecular diffusion reported in the literature is shown in Table 2.

TABLE 2 - APPARENT COEFFICIENTS OF MOLECULAR DIFFUSION (after Barbour, 1981)

REFERENCE	SOURCE	CONTAMINANT	SOIL TYPE	D* (m^2/s)
de Josselin de Jong, 1958	Lab Test	Saline Solution	0.08 mm diameter	7×10^{-9}
Simpson, 1962	Lab Test	Indigo Carmine Dye	Porous Block	6×10^{-9}
Ogata, 1964	Lab Test	Radioactive Phosphorus	Uniform Sand	8×10^{-10}
Manheim, 1970	Lab Test reported in literature	Monovalent and Trivalent, - and + ions	Fine Sands	$2 - 6 \times 10^{-10}$
Lerman & Tangiguchi, 1972	Case History	Sr-90	Lake Sediment (Clay and Sand)	$2 - 6 \times 10^{-10}$
Goodall & Quigley, 1977	Case History Literature	Ca^+, Mg^+, K^+ and alkali Chlorides	Silty Clay	$2.2 - 13 \times 10^{-11}$ $2.4 - 4.3 \times 10^{-11}$
Freeze & Cherry, 1979	Literature Review	--------	-------	1×10^{-11} to 1×10^{-10}
Lee et al	Assumption	Saline Solution	Fine Sand	7.3×10^{-10}
Gillham et al, 1984	Lab Test	^{36}Cl	Bentonite Sand Mixture	$8-10 \times 10^{-9}$

On the basis of the values reported in the literature, the following discrete probabilistic estimate was developed for the apparent coefficient of molecular diffusion:

- $D^* = 1 \times 10^{-11}$ m^2/s with a probability of 0.1
- $D^* = 1 \times 10^{-10}$ m^2/s with a probability of 0.8
- $D^* = 5 \times 10^{-10}$ m^2/s with a probability of 0.1

The estimated probability distribution for the diffusion coefficient is somewhat pessimistic; however, due to the relatively short time frame being examined (75 years maximum), diffusion will not significantly contribute to the advance of the brine front, except at very low advective flow velocities. However; if the advective velocity is low enough to make diffusion significant, then the migration distance for the brine front would be relatively small.

3.3.1.4 Dispersivity, α

Dispersivity is a scale dependant parameter. Dispersivity in the direction of flow (longitudinal dispersivity, α_L) is generally different than the dispersivity in the direction perpendicular to the flow (transverse dispersivity, α_T). In the case of one-dimensional flow, only the longitudinal dispersivity is required. Freeze and Cherry (1979) indicate that dispersivity is "the most elusive of the solute transport parameters". Dispersivity may be back-calculated from column tests; however, due to the scale effects noted above, these values may have little relevance in the field. Field scale measurements of dispersivity can be obtained by: 1) single well withdrawal-injection tests, 2) natural gradient tracer tests, 3) two-well recirculating withdrawal-injection tests, and 4) two-well pulse tests. All of these field tests are time consuming and expensive to perform. Further, the results of these tests are dependant on the mathematical model used to calculate the dispersivity, and the scale of the test. For these reasons, the dispersivity values used in the discrete probabilistic analysis were determined on the basis of values reported in the literature. A summary of dispersivity values reported in the literature is shown in Table 3.

On the basis of the values shown in Table 3, the following discrete probabilistic estimate was developed for the dispersivity of the soils:

- $\alpha = 1$ m with a probability of 0.1
- $\alpha = 5$ m with a probability of 0.8
- $\alpha = 30$ m with a probability of 0.1

3.3.1.5 Porosity, n (Deterministic Variable)

The porosity of the soil was assumed to be a deterministic value in the simulation. An examination of the water contents from samples obtained in the field program yielded a range of porosity from approximately 0.4 to 0.5. The porosity value (n) used in the solute migration analysis was 0.45. The assumed value agrees with that reported by Maathuis Jaworski and Zlipko (1993).

TABLE 3 - DISPERSIVITY VALUES (after Barbour, 1981)

Scale	Method	Longitudinal Dispersivity (α_L), metres	Reference
Small Sample (< 2m)	Column Test	0.01	Pickens et al, 1980
	Column Test	0.002	Pickens, 1980
2 - 4 m	Single well test	0.1 to 0.5	Fried, 1975
	Single Well Point Dilution Test	0.1	Pickens et al, 1980
4 - 20 m	Two-well Test	38.1	Grove and Beetem, 1971
	Multiple Well Test	4.25 to 11.0	Fried, 1975
	Two-well Test	0.5	Pickens et al, 1980
20 - 100 m	Single well test with geophysical monitoring	12.0	Fried, 1975
> 100 m (usually several km)	Modelling	61.0	Bredehoeft and Pinder, 1973
		21.3	Pinder, 1973
		91.0	Robertson and Barraclough, 1973
		30.5	Konokow and Bredehoeft, 1974
		15.0	Fried, 1975
		6.7	Segal and Pinder, 1976
		3.0 6.1	Schwartz, 1977

3.3.2 Implementation of Simulation

The analysis was conducted using a computer program to solve the ADE solute migration model for the C/C_0 ratio at various distances from the existing front at elapsed times of 25, 50 and 75 years. The location of the solute front was taken as the point where C/C_0 was less than 0.001. If the concentration of brine (C_0) is taken as 300 000 mg/L, then the assumed concentration at the brine front would be 300 mg/L, which corresponds to the Saskatchewan drinking water objectives (Saskatchewan Environment (1980)). Obviously, if a higher C/C_0 ratio is used to define the front of the plume, the computed travel distances of the brine front would be smaller.

After the solution was generated for all 81 scenarios, at each of the three elapsed time values, the travel distance for the front of the plume was determined along with its associated probability. The trials were then ranked by migration distance and a cumulative probability distribution was computed for each elapsed time, as illustrated in Figure 5.

4.0 INTERPRETATION OF RESULTS

The cumulative probability distributions for elapsed times of 25, 50 and 75 years are shown on Figure 5. This figure shows the cumulative probability on the vertical axis and the travel distance of the brine front from d_0 (current position of the brine front) on the horizontal axis. The minimum travel distance (d) for off-site brine migration to occur is approximately 720 m, as shown on the graph. The probability of off-site brine migration can be interpreted from the this figure as:

- approximately 0% probability of off-site brine migration in 25 years
- 2% probability of off-site brine migration in 50 years
- 8% probability of off-site brine migration in 75 years

The expected value for the travel distance of the solute plume would be:

- 100 m from d_0 in 25 years
- 160 m from d_0 in 50 years
- 215 m from d_0 in 75 years

Based on the discrete probabilistic simulation of brine migration from the TMF for the reference section selected, it appears that there is only a small probability that the brine front (defined by $C/C_0 = 0.001$) may migrate off-site, even assuming a 75 year remaining operating life. Assuming a remaining operating life of 25 years, there is no significant probability of off-site migration. Once the mine is decommissioned, the pre-mine groundwater flow regime is expected to be re-established and the migration of brine towards the northeast will be reduced.

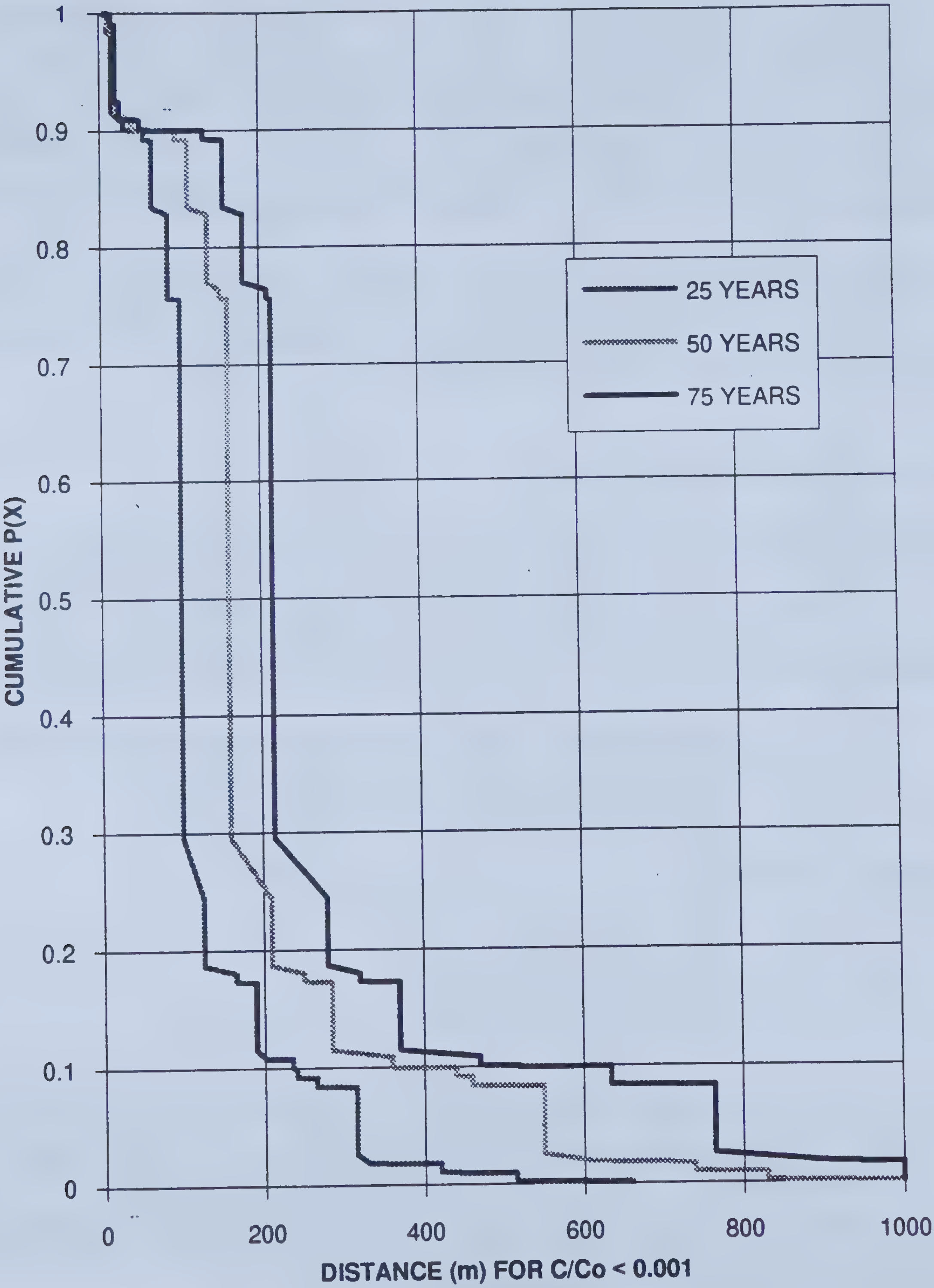

Figure 5: Cumulative Probability Distribution for Brine Front Migration

5.0 CONCLUSIONS

This paper has illustrated a practical methodology for explicitly quantifying the potential for off-site brine migration for an operating potash mine. The methodology is simple and efficient. By explicitly quantifying the uncertainty in the dominant inputs to the solute transport model and integrating this uncertainty through to the estimate of travel distance using discrete probabilistic simulation, the analysts were able to explicitly quantify the expected value and the uncertainty in our estimates. This is clearly a more robust answer than would have been achieved using a deterministic analysis framework.

The analysis utilized a relatively simple solute transport model and simplifying assumptions regarding the soil stratigraphy and other inputs. If this first order calculation had indicated a significant potential for off-site brine migration, further analyses would have been undertaken. Using a relatively simple model within a probabilistic framework provided a technically sound analysis in a cost efficient manner.

The brine migration in the area under consideration is currently being monitored using surface electromagnetic (EM) surveys. These surveys will assist in the calibration/verification of the modelling.

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DEVELOPMENT OF ENVIRONMENTAL TECHNOLOGY IN SUPPORT OF THE DECOMMISSIONING OF URANIUM TAILINGS AT CLUFF LAKE MINE

Presented by:

Brian Ayres

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Brian Ayres, S. Lee Barbour, Brenda Bews, and M. O'Kane
Unsaturated Soils Group
Department of Civil Engineering
University of Saskatchewan
Saskatoon, Saskatchewan

Curt Andrews and Ron Barsi
Cogema Resources Inc.
Saskatoon, Saskatchewan

DEVELOPMENT OF ENVIRONMENTAL TECHNOLOGY IN SUPPORT OF THE DECOMMISSIONING OF URANIUM TAILINGS AT CLUFF LAKE MINE

Brian Ayres[1], S. Lee Barbour[2], Brenda Bews[3], M. O'Kane[3], Curt Andrews[4], Ron Barsi[5]

ABSTRACT

Cogema Resources Inc., together with the Unsaturated Soils Group at the University of Saskatchewan, initiated a multi-year research program at the Cluff Lake Mine during the summer of 1995. The objective of the research program is to investigate three key areas of environmental technology related to the decommissioning of uranium tailings in northern Saskatchewan. The first area of research is to evaluate methods for predicting the net flux of water across the tailings/atmosphere boundary. This research area consists of two phases; Phase I involves field monitoring of two sites (a tailings surface and a natural surface), while Phase II consists of numerical modelling. The second area of research is the characterization of the geochemistry and the development of methods for estimating the potential (leachable) contaminant mass. The last area of research is the characterization of paste tailings and involves determining the hydraulic and mechanical properties of the tailings. This paper briefly outlines the research program with a particular emphasis on the field instrumentation program currently being undertaken at Cluff Lake Mine.

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[1] Graduate Student, Department of Civil Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan, Canada, S7N 5A9

[2] Professor of Civil Engineering, Department of Civil Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan, Canada, S7N 5A9

[3] Research Engineer, Unsaturated Soils Group, Dept. of Civil Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan, Canada, S7N 5A9

[4] Technical Manager, Cogema Resources Inc., 817-825 45th Street West, Saskatoon, Saskatchewan, Canada, S7K 3X5

[5] Manager of Environment, Cogema Resources Inc., 817-825 45th Street West, Saskatoon, Saskatchewan, Canada, S7K 3X5

INTRODUCTION AND BACKGROUND

A critical element in mine development is the design of containment facilities for waste rock and mine tailings. These materials have the potential to release contaminants to natural groundwater and surface water systems which in turn provide pathways for these contaminants to biological receptors. It is important that engineering technology be developed in this area in order to enhance the level of environmental protection provided in the design of waste management facilities.

Cogema Resources Inc. and the University of Saskatchewan signed a contract in January, 1995 to initiate a three year research program at Cluff Lake Mine. The research program consists of three key areas in which environmental-technology related to the decommissioning of uranium tailings can be developed within Saskatchewan. The three studies involve defining the chemical and hydraulic response of the tailings, as well as the physical characterization of the waste material. The studies are not intended to be comprehensive in their coverage of technical concerns related to the decommissioning of uranium tailings; rather, they focus on key technical issues of concern industry-wide.

The purpose of this paper is to briefly describe the three areas of the research program and describe in detail the field instrumentation portion of the program. At this stage only a small quantity of field data has been collected. Therefore, the focus of this paper will be on the design of the field instrumentation program and the field installation.

RESEARCH PROGRAM - OVERVIEW

The objective of the research program is to investigate three key areas of environmental technology related to the decommissioning of uranium tailings in northern Saskatchewan. The first area of research is to evaluate methods for predicting the net flux of water across the tailings/atmosphere boundary. This research area consists of two phases; Phase I involves field monitoring of two sites (a tailings surface and a natural surface), while Phase II consists of numerical modelling. The second area of research is the characterization of the geochemistry and the development of methods for estimating the potential (leachable) contaminant mass. The last area of research is the characterization of paste tailings and involves determining the hydraulic and mechanical properties of the tailings. In the next sections the key background issues, methodology, and the contribution of each study to technology development are described.

Hydraulic Definition

Defining the hydraulic response of the tailings is critical to the prediction of contaminant release and transport to the environment. The net flux of water across the tailings surface controls the volume of effluent generated and the degree of saturation in the waste material. This latter condition controls rates of radon release as well as rates of oxygen ingress and subsequent acidification of acid generating waste.

In order to more accurately define this flux of water a two phase study is being undertaken. The first phase involves the establishment of instrumented field sites at the Cluff Lake Tailings Management Area (TMA). The instrumentation includes site specific meteorological measurements as well as detailed monitoring of the temperature, water content, and water pressure within tailings and natural surface soils. The monitoring will continue over the three year duration of the research program.

The second phase of this study is to verify the applicability of a previously developed numerical model for flux prediction. This model (SoilCover, (MEND, 1993)) was developed at the University of Saskatchewan as part of the MEND program. Once verified and calibrated for this site it should become a useful tool for the design of the final tailings configuration and cover.

The specific aspects of technology development associated with this project are: (1) the development of instrumentation systems for TMA monitoring, (2) the development and verification of software for flux predictions, and (3) the development of a methodology for the design of surface covers for decommissioning of uranium mine waste in northern Saskatchewan.

Chemical Definition

One key technical concern related to the performance of the TMA following decommissioning is the definition of the mass of Ra-226 which will be leached from the tailings with time. This is a critical issue for all methods of tailings disposal including in-pit disposal methods. In a conventional TMA, like Cluff Lake, the concentration of Ra-226 within the tailings as it is leached by surface and groundwater inflows must be known in order to predict mass loadings to the environment following decommissioning. As a result, there is a need for an accurate and reliable technique by which the "leachable" fraction of Ra-226 released from mine tailings can be determined.

A laboratory program will be conducted in which conventional tailings or paste tailings will be tested. These tailings will be placed in conditions similar to those present in the field and would then be allowed to leach through diffusion into a reservoir containing groundwater. This technique has been developed jointly by the University of Saskatchewan and the National Hydrology Research Institute.

This program will produce a procedure by which the tailings source chemistry and its total potential contaminant loading to the environment can be estimated. Many current predictions of contaminant loading to the environment utilize a constant source concentration. If a decrease in source concentration due to leaching at the tailings boundaries is utilized, significantly lower loadings to the environment will be predicted.

Physical Definition

The search for innovative techniques for tailings containment initially led to the engineering of the TMA through the use of cutoffs, liners, or pervious surrounds. In recent years, however, there has been increased interest in engineering the properties of the tailings themselves (Robinsky, 1975; Barbour et al., 1993). In many instances the optimum performance of the TMA with respect to low hydraulic conductivity, minimal influx of water, uniform hydraulic and geochemical properties, and saturated conditions can be enhanced by controlling the properties of the tailings during deposition. One of these new placement technologies is the use of paste tailings.

This study will utilize the paste tailings currently being considered for deposition at the Cluff Lake TMA. The testing will include not only standard geotechnical properties, but also hydraulic properties (moisture retention, hydraulic conductivity, etc.), thermal properties (thermal conductivity, specific heat) and geochemistry. Field verification of the laboratory characterization will also be required, particularly as it relates to the depositional nature of the paste tailings. Numerical modelling of the role of the paste tailings in controlling seepage and contaminant transport from the TMA will then be undertaken.

The future design of TMAs for uranium mines includes the ability to "design" the properties of the tailings themselves. The results from this program will provide a fundamental understanding of the properties and benefits of paste tailings on the design and performance of a TMA.

FIELD INSTRUMENTATION PROGRAM

The main objective of the field monitoring program is to characterize the soil/atmosphere flux boundary conditions of the mine tailings and natural surface soils at Cluff Lake Mine. Additional objectives are as follows:

(1) To install and monitor field instrumentation on the tailings and natural surface soils,

(2) To measure the net flux of water across the surface of the mine tailings and natural soils, and

(3) To establish a comprehensive set of field data for field response modelling.

The quantity of water which flows downward through the tailings can be defined as the net infiltrative water flux for groundwater recharge and leachate production. The net infiltrative flux is controlled by the water balance at the soil surface which includes precipitation, runoff, infiltration, evaporation and/or evapotranspiration, and changes in soil moisture storage. In general terms, the net infiltrative flux through a specified depth and time period can be calculated as the total precipitation less runoff, evapotranspiration and change in soil moisture storage. Therefore, site specific measurements of precipitation, runoff, evapotranspiration, and volumetric water content are required to properly evaluate net infiltrative fluxes.

Swanson (1995) demonstrated that accurate predictive modelling required an initial field response, or calibration stage. Field responses refer to conditions that develop within a soil system such as changes in moisture content, matric suction, and temperature. The ability to accurately describe field conditions must first be demonstrated before a model can be used to predict net infiltrative fluxes. As a result, the input parameters required by the model lay the foundation for the field instrumentation program.

General Features of Field Program

The general features of the field monitoring program at Cluff Lake Mine are: (1) data acquisition systems, (2) back-up monitoring methods, (3) the selection of the sampling frequency, and (4) the establishment of two monitoring sites.

The use of automated systems for data collection greatly reduce the need for human intervention and in particular, the requirements of mine site personnel. A data acquisition system usually consists of a datalogger, multiplexer, and storage module, contained in an environmentally sealed enclosure, and a solar panel/rechargeable battery power source. A multiplexer increases the number of sensors that may be scanned by the datalogger. A storage module reduces the frequency of trips required to download data and in the event of a power loss, will retain all stored data.

In order to ensure that the field data is representative of actual conditions, more than one method should be used to monitor a given parameter. If only one method is available for monitoring, then more than one of the selected instruments should be installed. Problems such as defective or poorly calibrated instrumentation can be detected if back-up systems are included in the field program. Periodic manual measurements during site visits allows for error checking in the automated monitoring systems.

Selection of the proper sampling frequency is another key element in any field instrumentation program. The ultimate use of the data aids in establishing the need for measuring fluctuations in the signals. For example, wind speed often fluctuates rapidly and as a result, a high rate of sampling is required for an accurate representation of wind speed. For this study, sampling frequencies will be established by initially collecting data at a rapid pace. Once the data has been reviewed, the rate of data collection will be slowed to meet the necessary data requirements while still maintaining sufficient accuracy. A reduced rate of sampling maximizes the memory space of the storage modules.

The field program at Cluff Lake Mine involves the establishment of two monitoring sites, one site on the uranium tailings and one on the natural surface soils (sandy till). The sites were situated so that the depth to the water table was maximized, allowing for the monitoring of an unsaturated soil system. The purpose of the natural surface monitoring site is to provide a natural analogue to the performance of a potential till cover.

Design of Field Program

The design of the field instrumentation program involved the selection of robust instruments that required minimal calibration and maintenance. The methods and instruments selected for the monitoring of climatological and hydrological conditions at Cluff Lake Mine are discussed below.

Climatological Monitoring

Site climatic conditions are measured with a fully automated weather station. Meteorological measurements include air temperature, relative humidity, wind speed and direction, net radiation, and precipitation. These measurements are used as input to SoilCover for the calculation of potential evaporation (Swanson, 1995). The temperature and relative humidity probe is housed in a radiation shield to minimize the effects of solar radiation. All sensors are connected to a data acquisition system.

The automated weather station collects hourly averages of temperature, relative humidity, wind speed and direction, and net radiation. Data is output as rainfall occurs in order to generate intensity-duration curves for rainfall events. The daily maximum and minimum values of air temperature, relative humidity, and wind speed are recorded, along with the total precipitation for the day. In order to check the validity of these measurements, comparisons will be made with data collected from the Cluff Lake Meteorological Station.

Hydrological Monitoring

Evaporation - Soil evaporation is a coupled process which depends on both atmospheric conditions (i.e. net radiation, temperature, humidity, wind speed) and soil properties (i.e. soil water potential, hydraulic conductivity and moisture retention properties). If a soil surface is saturated, water can evaporate at a rate equivalent to that of a free water surface (Penman, 1948). This rate, often termed the potential evaporation rate, represents the upper limit at which water can be supplied to the atmosphere and is solely a function of atmospheric demand. As the soil dries and becomes unsaturated, the rate of evaporation declines below the potential rate. This actual rate of evaporation depends on both atmospheric conditions and soil properties (Wilson, 1990).

The field program at Cluff Lake Mine utilizes the Bowen Ratio energy balance method to measure actual evaporative fluxes (Bowen, 1926). The Bowen Ratio instrumentation, developed by Campbell Scientific Inc. (1988), is illustrated in Figure 1. It is a self-contained tripod structured meteorological monitoring system. Variables measured include air temperature (at two heights), vapour pressure (at two heights), net radiation, and soil heat flux. The Bowen Ratio system measures these variables every twenty minutes and operates during the summer months only.

Matric Suction - Field matric suction is a measurement of the negative water pressure within a soil system. These measurements are important because matric suction describes the stress state within the soil and the hydraulic gradients. In other words, a change in the degree of saturation or water content of a soil system is caused by a change in matric suction within the soil. In addition, Swanson (1995) demonstrated that field matric suction measurements were useful for verifying the actual evaporative flux predicted by SoilCover.

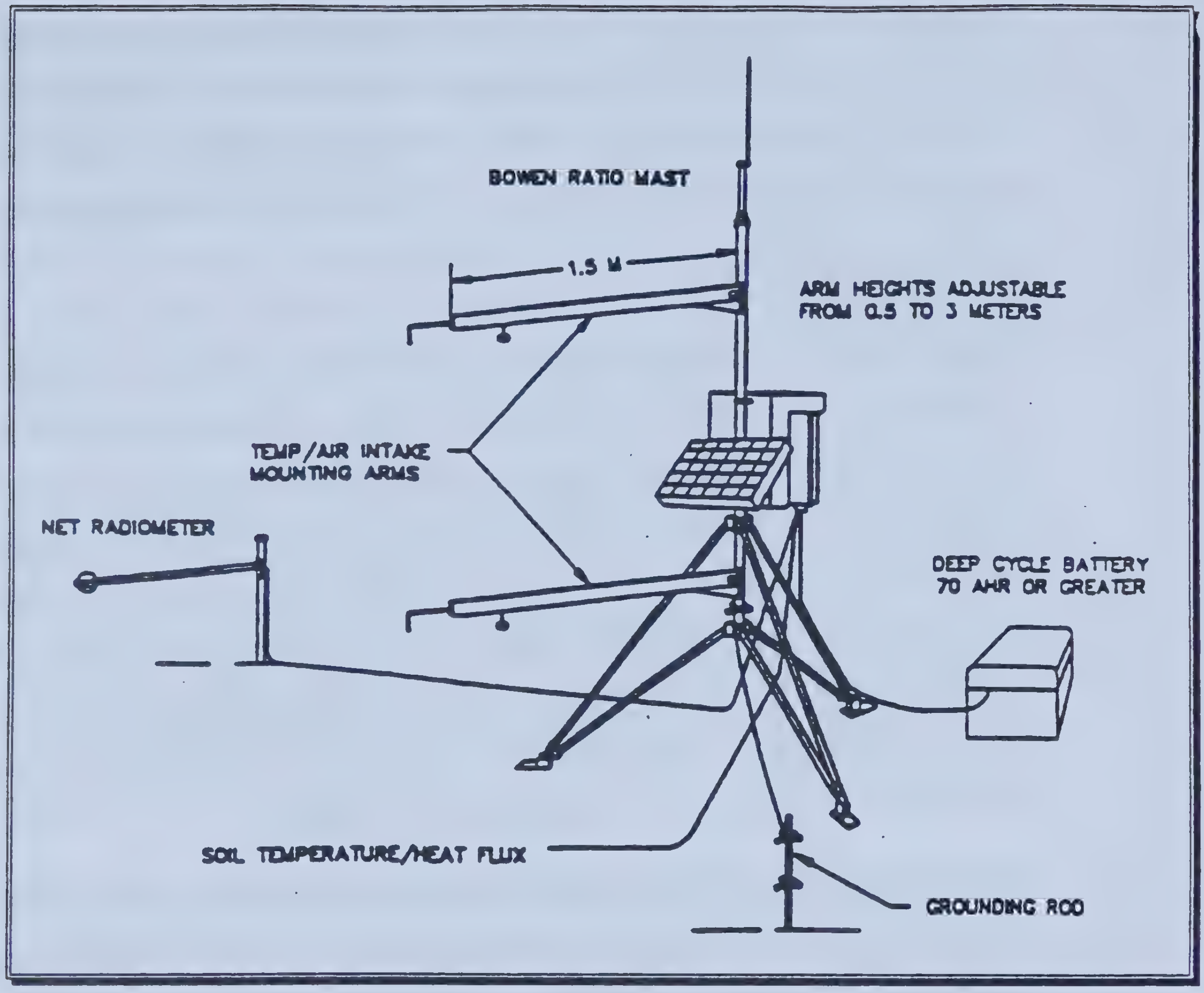
BOWEN RATIO MAST
1.5 M
ARM HEIGHTS ADJUSTABLE FROM 0.5 TO 3 METERS
TEMP/AIR INTAKE MOUNTING ARMS
NET RADIOMETER
DEEP CYCLE BATTERY 70 AHR OR GREATER
SOIL TEMPERATURE/HEAT FLUX
GROUNDING ROD

Figure 1. Schematic of the Bowen Ratio System (after Campbell Scientific Inc., 1988).

Measurements of insitu soil matric suction are made with thermal conductivity sensors and jet-fill tensiometers. The thermal conductivity sensor indirectly measures the matric suction in a soil while also measuring the temperature of the soil. These sensors are monitored continuously with a data acquisition system. Laboratory calibration of each sensor is essential in order to obtain representative field measurements of matric suction. Jet-fill tensiometers directly measure the negative pore water pressure in a soil. The tensiometers will be used to validate measurements by the thermal conductivity sensors.

Soil Temperature - In order to accurately predict heat fluxes with SoilCover, field measurements of soil temperature are required (MEND, 1993). A multi-point thermistor string is used in this program to verify the temperatures recorded by the thermal conductivity sensors. Each string consists of eight beads (thermistors) located at user-specified depths. The thermistor strings are connected to a data acquisition system for continuous monitoring of soil temperature.

Water Content - Measurements of insitu volumetric water content are needed to determine changes in soil moisture storage. Methods used to measure volumetric water content need to be fast, reasonably accurate, and nondestructive. The methods selected for the field program at Cluff Lake Mine are time domain reflectometry (TDR) and the neutron hydroprobe. TDR was selected because measurements at several depths within the soil can be made automatically with one TDR unit, calibration is not essential, and the system requires little maintenance. Neutron probe access tubes provide manual measurements of volumetric water content, which can be used to verify values obtained by TDR.

The principles behind measurement of volumetric water content using TDR have been described in detail elsewhere (Topp et al., 1980; Roth et al., 1990; Look and Reeves, 1992); they are reviewed briefly here. TDR is used to measure the apparent dielectric constant of soil, which is closely related to volumetric water content. Water has a dielectric constant on the order of 80, whereas the dielectric constant of soil solids is typically 3 to 5 (Topp et al., 1980). Consequently, changes in volumetric water content affect the apparent dielectric constant of soil. This study uses three-wire TDR probes and the TRASE System to monitor insitu volumetric water contents. Although calibration of TDR systems is not essential, both field and laboratory calibrations will be performed to secure accurate moisture readings.

In order to use a neutron moisture probe as a tool to measure water content of a soil an access tube must first be installed into the soil. The access tube allows the probe to be lowered into the soil. Field calibration of the neutron probe access tubes is essential. The neutron moisture gauge used in this study is the CPN 503/503DR Hydroprobe manufactured by Campbell Pacific Nuclear Corporation of Martinez, California.

Runoff - Local surface reservoirs will be installed near each of the main instrumentation locations at Cluff Lake Mine. A schematic of the design of the surface runoff

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measurement reservoirs is illustrated in Figure 2. The reservoirs are designed to collect runoff from storm events during non-freezing conditions. Surface runoff that occurs above the contributing areas is diverted away. The cross pieces which mark the lower boundary with respect to surface runoff of the contributing areas collect runoff which is then stored in large plastic pails below the surface. The volume stored in the pails is recorded and used to calculate local surface runoff from the contributing area.

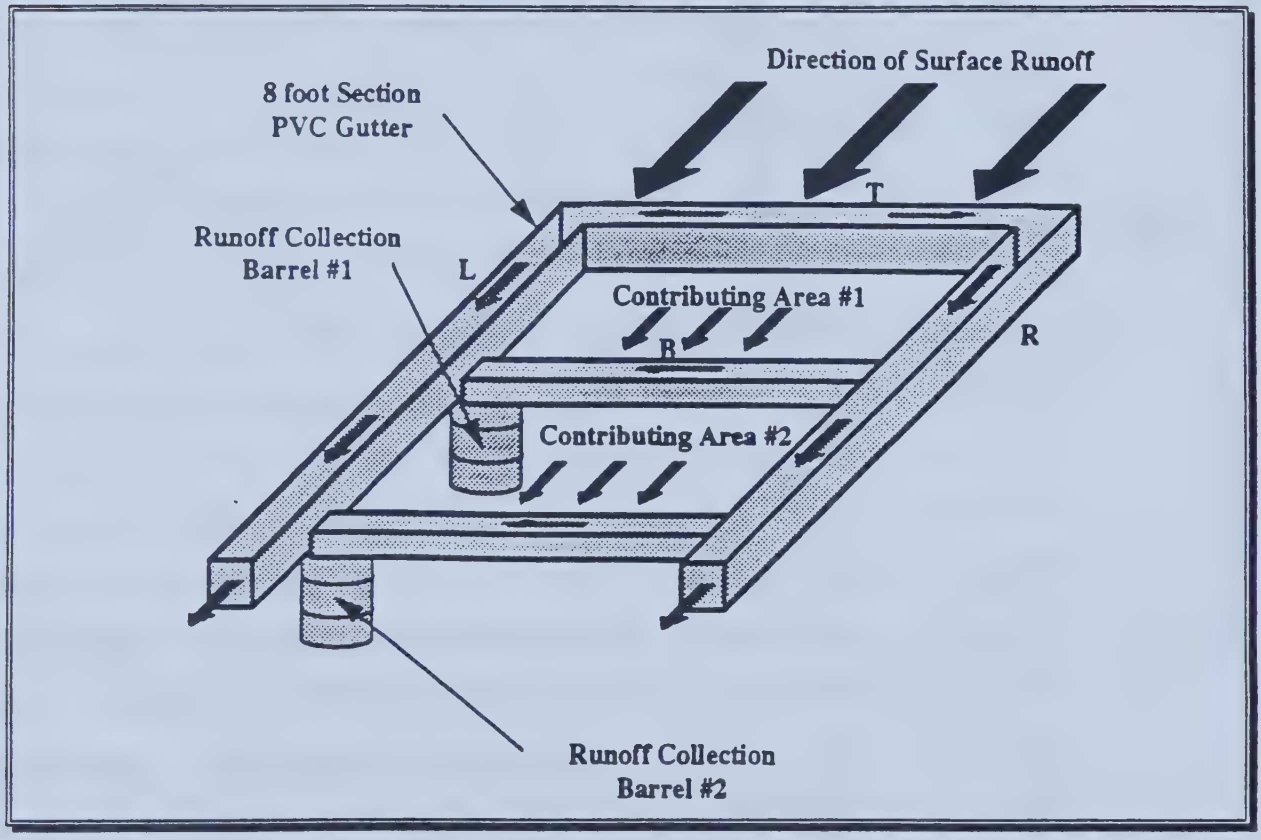
Direction of Surface Runoff
8 foot Section
PVC Gutter
T
Runoff Collection
Barrel #1
L
Contributing Area #1
B
R
Contributing Area #2
Runoff Collection
Barrel #2

Figure 2. Schematic of the local surface runoff reservoirs (after O'Kane, 1995).

Field Installation

Field instrumentation of the natural surface soils and uranium tailings began in July, 1995. Site visits to install instrumentation took place from July, 1995 to September, 1995. A significant portion of the installation was completed during this time. However, site visits during the spring of 1996 will be required to complete the installation.

Figure 3 illustrates the location of all field instrumentation that will be installed at Cluff Lake Mine. The natural soil monitoring site (NSMS) and tailings monitoring site (TMS)

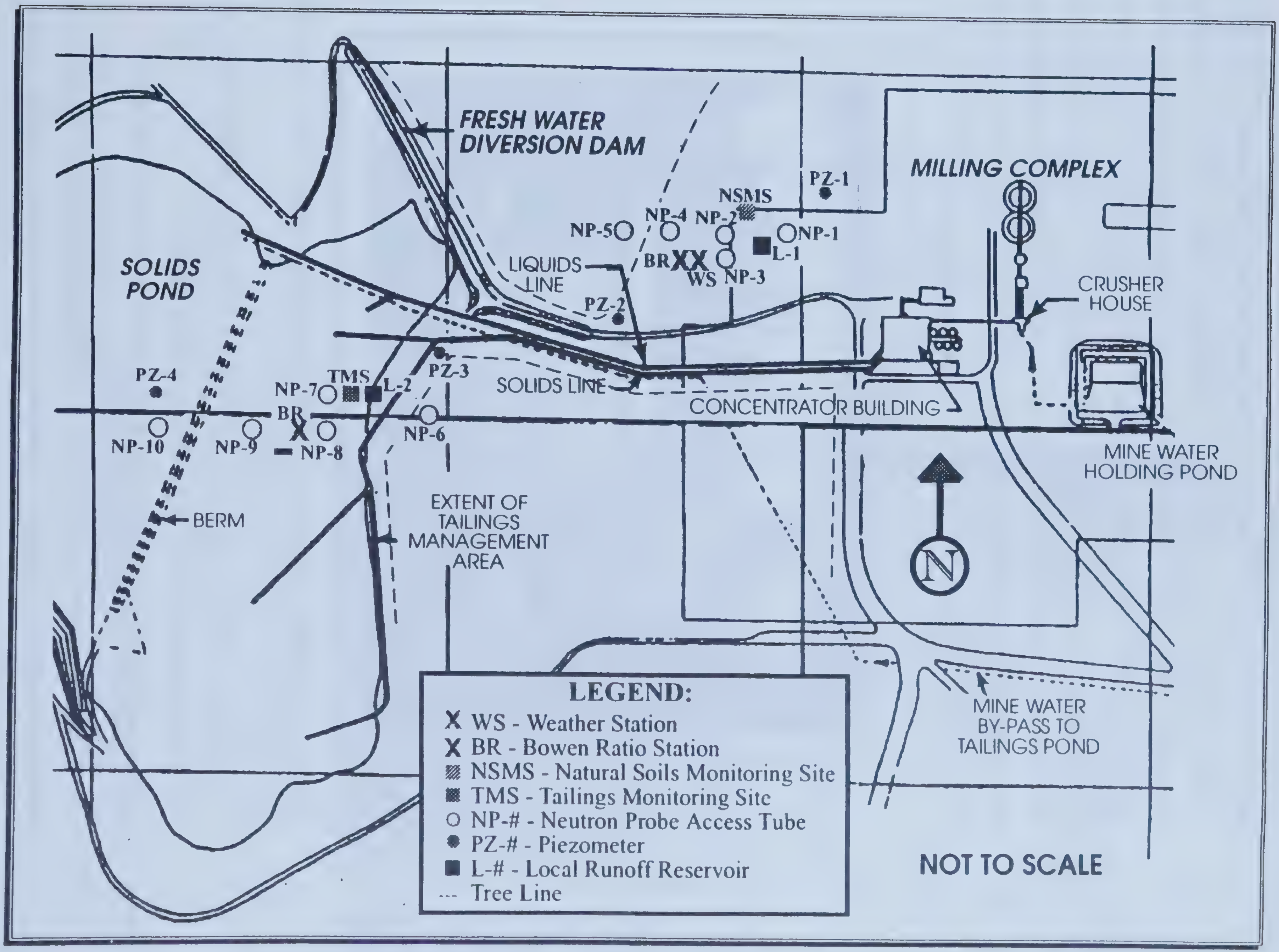
FRESH WATER DIVERSION DAM
MILLING COMPLEX
SOLIDS POND
PZ-1
NSMS
NP-5
NP-4
NP-2
NP-1
L-1
BR
WS
NP-3
LIQUIDS LINE
PZ-2
CRUSHER HOUSE
PZ-4
TMS
NP-7
L-2
PZ-3
SOLIDS LINE
CONCENTRATOR BUILDING
BR
NP-10
NP-9
NP-8
NP-6
MINE WATER HOLDING POND
BERM
EXTENT OF TAILINGS MANAGEMENT AREA
N
LEGEND:
X WS - Weather Station
X BR - Bowen Ratio Station
▨ NSMS - Natural Soils Monitoring Site
▩ TMS - Tailings Monitoring Site
○ NP-# - Neutron Probe Access Tube
● PZ-# - Piezometer
■ L-# - Local Runoff Reservoir
--- Tree Line
MINE WATER BY-PASS TO TAILINGS POND
NOT TO SCALE

Figure 3. Site plan showing the location of field instrumentation at Cluff Lake Mine (after Ayres, 1995).

are the main instrumentation locations. Each instrumentation site contains eight thermal conductivity sensors, eight TDR probes, two thermistor strings, and two neutron probe access tubes. Figure 4 is a photograph of the NSMS including its data acquisition system. The weather station was installed next to the NSMS. The location of the Bowen Ratio station will alternate between the NSMS and TMS locations. All of the above mentioned instrumentation, except for the two access tubes next to the NSMS, were installed during the summer of 1995. Additional neutron probe access tubes were installed in the tailings in order to provide greater coverage of the moisture conditions in the TMA.

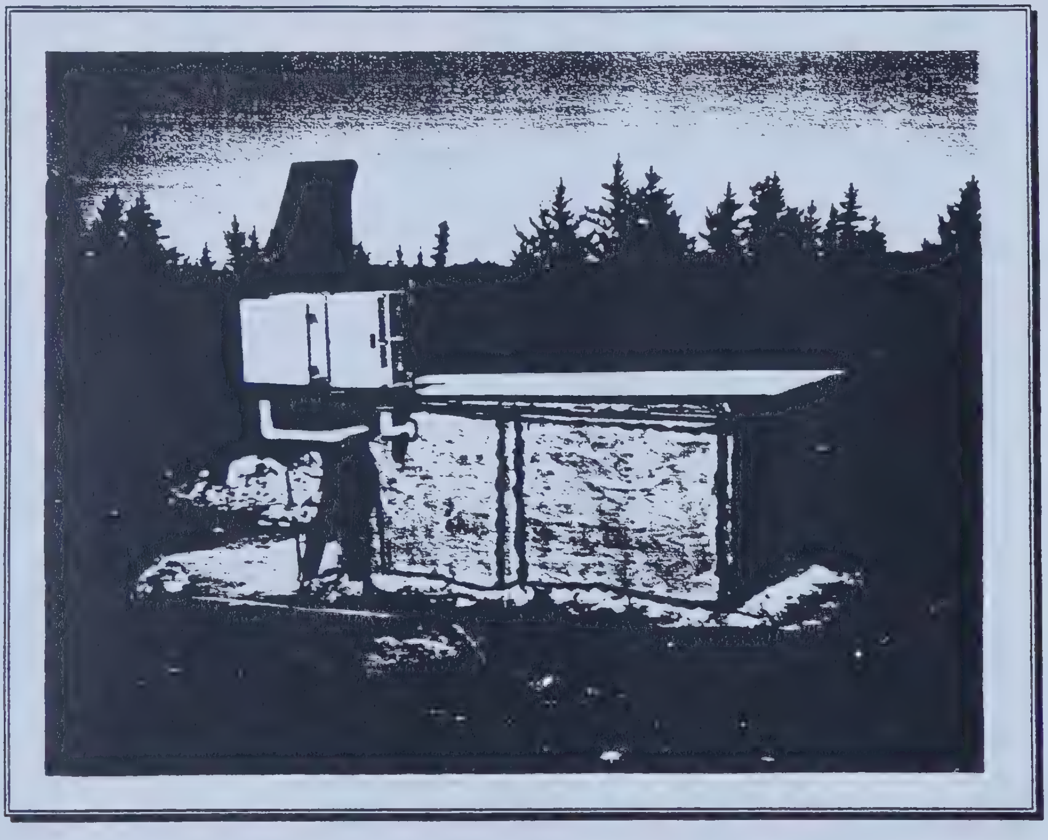

Figure 4. Photograph of the access box culvert and data acquisition systems at the natural soils monitoring site (after Ayres, 1995).

The installation of the thermal conductivity sensors, TDR probes, thermistor strings, and neutron probe access tubes are discussed in more detail below.

Thermal Conductivity Sensors and TDR Probes

NSMS - The thermal conductivity sensors and TDR probes were installed laterally into the natural soils as shown in Figure 5. A wooden box culvert installed vertically into the till

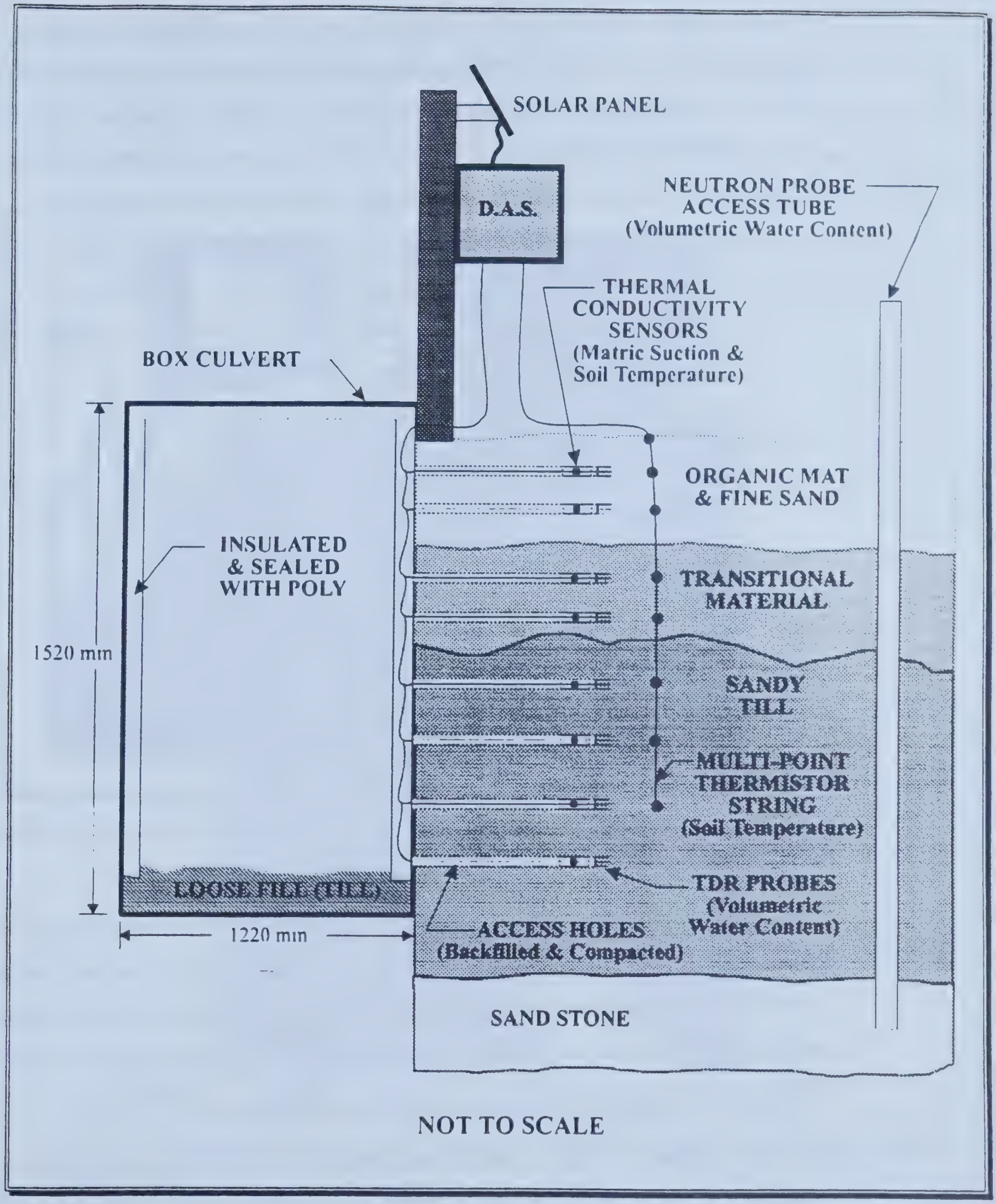
SOLAR PANEL
D.A.S.
NEUTRON PROBE ACCESS TUBE (Volumetric Water Content)
THERMAL CONDUCTIVITY SENSORS (Matric Suction & Soil Temperature)
BOX CULVERT
ORGANIC MAT & FINE SAND
INSULATED & SEALED WITH POLY
TRANSITIONAL MATERIAL
1520 mm
SANDY TILL
MULTI-POINT THERMISTOR STRING (Soil Temperature)
LOOSE FILL (TILL)
TDR PROBES (Volumetric Water Content)
1220 mm
ACCESS HOLES (Backfilled & Compacted)
SAND STONE
NOT TO SCALE

Figure 5. Cross-section of the access box culvert and sensor installations at the natural soils monitoring site (after Ayres, 1995).

provided access to the soil profile. Horizontal excavations of 600 mm were made through holes in the box culvert and into the till material to minimize the influence of the box culvert. Figure 6 is a photograph showing the excavation of an access hole. Separate access holes were required for each thermal conductivity sensor and each TDR probe.

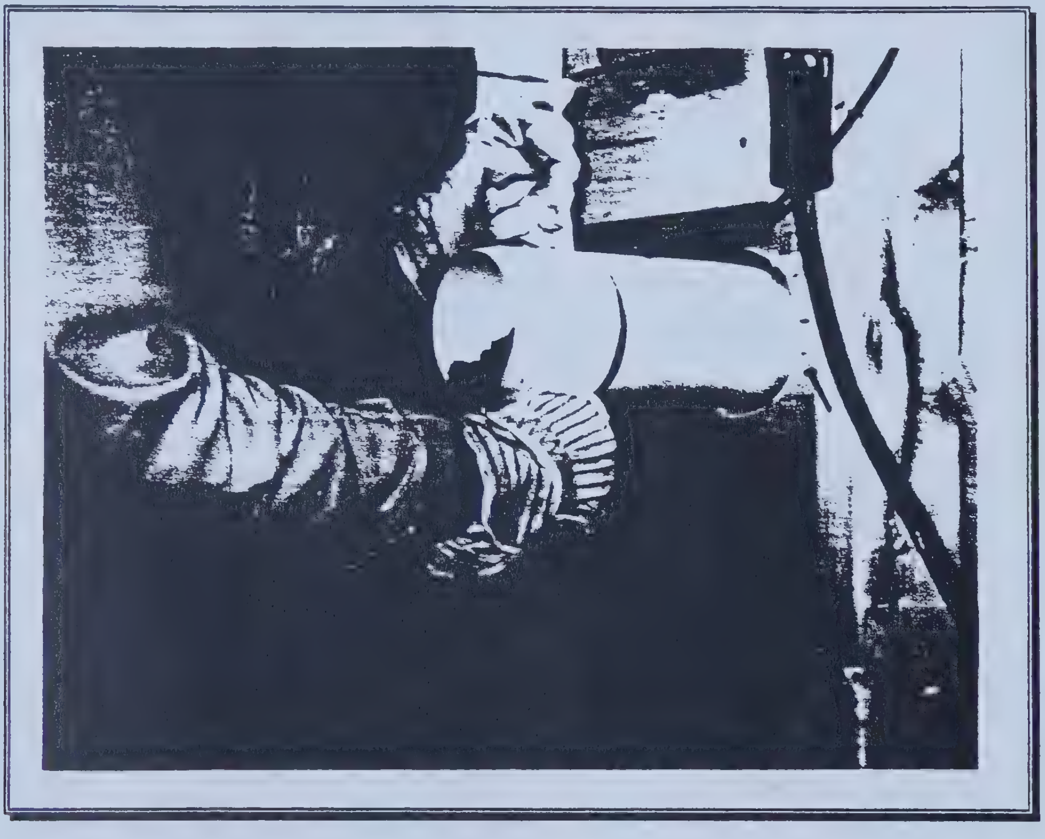

Figure 6. Photograph showing the excavation of an access hole at the natural soils monitoring site (after Ayres, 1995).

A small void was made at the end of the access hole for the installation of each thermal conductivity sensor. This allowed for the installation of the sensors into undisturbed material. All sensors were connected to a multiplexer controlled by a datalogger. The data acquisition system is powered by a solar panel/rechargeable battery. Currently, soil temperature and matric suction measurements are collected every six hours.

In order to obtain accurate moisture measurements with TDR, it was essential that the metal rods of the probe be in tight, intimate contact with the soil. Therefore, the probe rods were inserted directly into the soil to retain bulk density characteristics. The three-wire TDR probes were inserted directly into the upper layer of the till profile by simply pushing on the probes by hand. Insertion of the TDR probes into the till at lower depths, however, was much more difficult. An installation tool was used to create voids for each of the wires on the TDR probe. Figure 7 is a photograph of the installation tool and a TDR probe used in this study. The diameter of the rods on the tool were slightly smaller than the diameter of the wires on the probe, which ensured the probe wires remained in intimate contact with the soil. Figure 8 is a photograph showing a TDR probe installed at the end of an access hole.

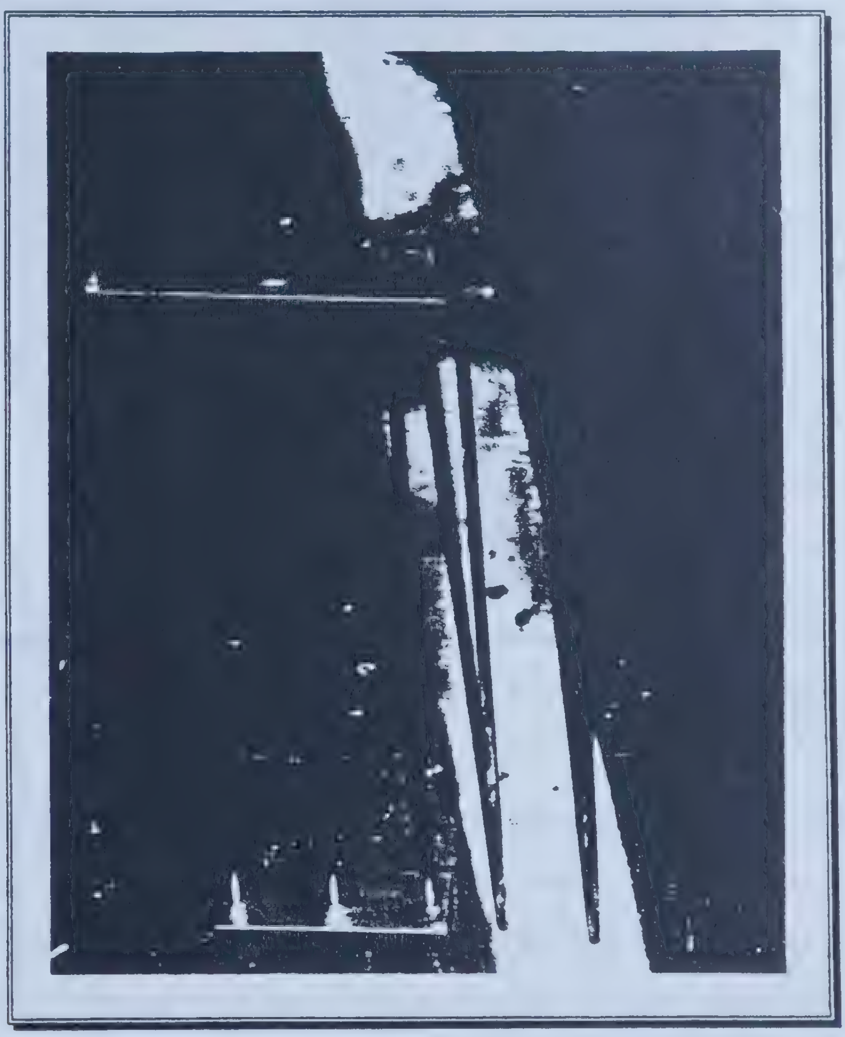

Figure 7. Photograph of the TDR installation tool and three-wire TDR probe (after Ayres, 1995).

The inside of the box culvert was insulated with fiberglass insulation and sealed with poly after backfilling and compacting all of the access holes. The objective was to minimize the influence of the atmosphere on the instruments installed laterally from the culvert. In addition, approximately 250 mm of till material was placed over a sheet of poly on the floor of the wooden box. The quality of the seal will be determined by the measurement of the temperature gradient across the wall of the box culvert. A thermistor string was installed inside the box and a second against the outside wall of the box culvert in the soil.

Figure 8. Photograph of a TDR probe installed at the end of an access hole (after Ayres, 1995).

TMS - The only difference between sensor installation at the NSMS and TMS is the fact that no access box culvert was used at the TMS. Instead, a trench was excavated by hand to gain access to the tailings profile. Once all thermal conductivity sensors and TDR probes were installed and access holes backfilled and compacted, the trench itself was backfilled and compacted.

Thermistor Strings

Two thermistor strings were installed next to each of the main instrumentation locations. A six inch diameter post-hole auger was used to excavate material for the insertion of the string. The thermistor string was placed against the edge of the hole (undisturbed material) so that soil temperatures will be representative of actual conditions. A careful attempt was made to backfill the material in the manner it was excavated and the material was compacted to its original insitu density as best as possible. The thermistor strings were connected to a multiplexer which is controlled by the same datalogger that controls the thermal conductivity sensors. Currently, soil temperature is recorded every six hours at eight depths. Figure 9 is an example of recent measurements collected from the NSMS.

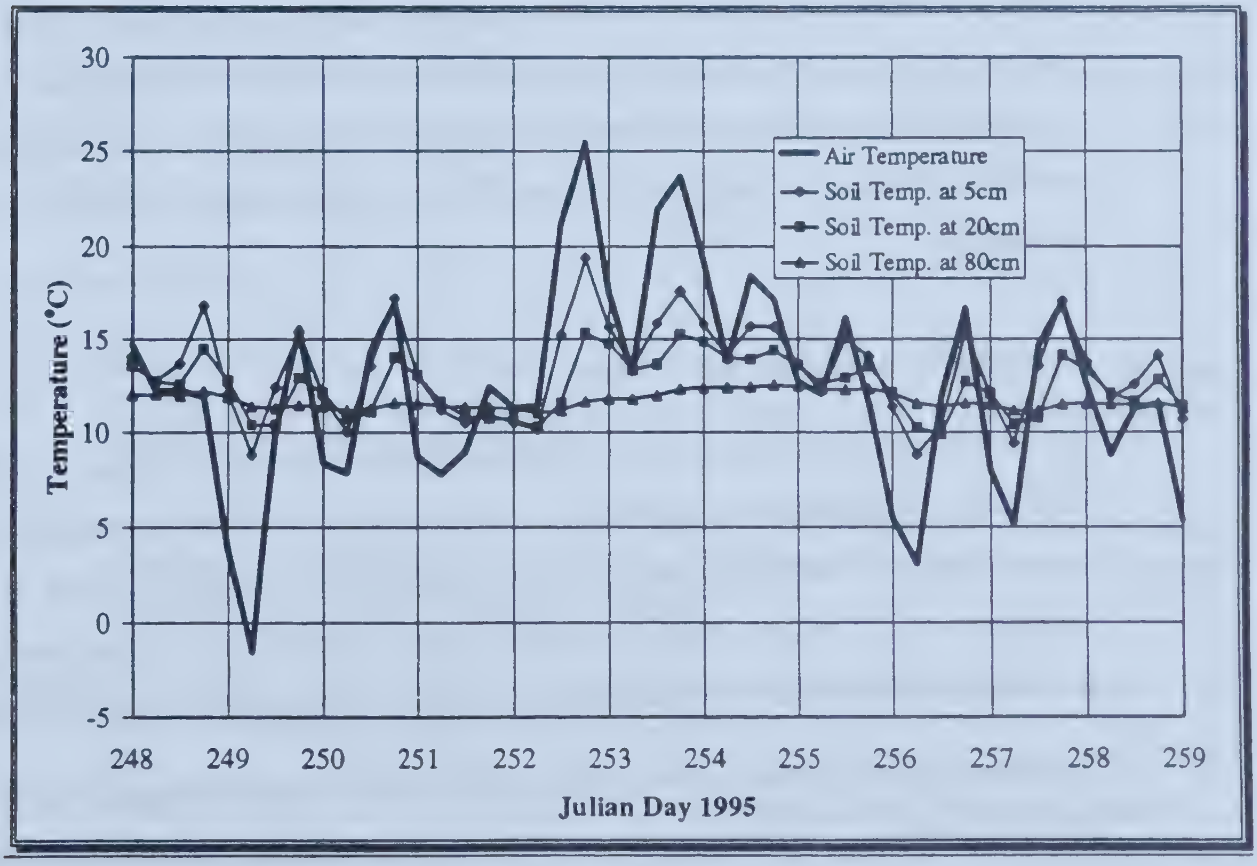

Figure 10. Air and soil temperature data collected at the natural soils monitoring site (after Ayres, 1995).

Neutron Probe Access Tubes

A total of ten aluminum access tubes will be installed at the Cluff Lake Mine. Two access tubes will be installed near each of the main monitoring sites and the remaining access tubes will be installed at other locations in the tailings and till. Water content measurements obtained at the NSMS and TMS will be verified with the matric suction measurements. Water content data from the remaining access tubes will be used to evaluate the soil system on a larger scale. To date, only the access tubes located on the tailings have been installed; the method of installation is described below.

A void was created by drilling a hole in the tailings with a 50 mm diameter auger. The aluminum tubing was placed in the void and pushed with a constant force to a depth of approximately 2000 mm. Care was taken to ensure the proper hole diameter was created. If the diameter is too large the resulting space between the outside wall of the access tube and the soil will allow moisture to migrate along the void. If the diameter is not large enough soil may compress and distort along the sides of the access tube. In both cases the resulting readings from the neutron gauge will not be representative of actual soil moisture conditions.

SUMMARY AND CONCLUSIONS

An overview of a multi-year research program initiated during the summer of 1995 at the Cluff Lake Mine has been presented. The objective of the research program is to develop environmental technologies for the decommissioning of uranium tailings in northern Saskatchewan. The key areas of research involve defining the chemical and hydraulic response of the tailings, as well as the physical characterization of the waste material.

To date, the primary focus of the work has been on the field instrumentation portion of the research program. The main objective of the field monitoring program is to characterize the soil/atmosphere flux boundary conditions of the uranium tailings and natural soils at Cluff Lake Mine. The design of the field program involved selecting robust and low maintenance instruments for the continuous monitoring of climatological and hydrological conditions at the mine site.

Presently, three M.Sc. graduate students and one research engineer are working on the research program. A significant portion of the installation of field instrumentation has been completed. Introductory modelling to evaluate the soil-atmosphere model's ability to simulate fundamental flow processes has been completed. A laboratory program including the design of a diffusion cell has been developed for characterization of the geochemistry of the uranium tailings.

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DRAFT ARD GUIDELINES FOR MINE SITES IN BRITISH COLUMBIA

William A. Price, John C. Errington, and Victor M. Koyanagi

Ministry of Energy, Mines and Petroleum Resources
Mine Review and Permitting Branch
4th Floor, 1810 Blanshard Street
Victoria, BC V8V 1X4

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BACKGROUND

Mine Regulation and Policy

Mining is a very productive land use generating significant wealth, while occupying a very small proportion of the provincial land base. In addition to maximizing returns to the provincial economy, the provincial government's mining policies include protection of the environment and where possible to make mining a temporary land use. For the most part, minesites can be returned to their pre-mining capability. This latter objective is enforced by current provincial mining legislation which requires that disturbed land and water resources be reclaimed to a level of productivity not less than that which existed previously, and that water released from the minesite meet long-term water quality standards.

Although the overall objective is to make mining a temporary land use, there are situations where the reclamation potential of mine facilities is limited or where long-term maintenance will be necessary. Any long-term maintenance requirement or "permanent" reduction of productivity must be minimized to the extent technically and economically feasible with current technology. These environmental impacts are considered in land use and approval decisions relating to proposed mine developments, in conjunction with other environmental and socio-economic impacts and benefits.

As part of the regulation of the mining industry, all mine proposals and closure plans are reviewed by inter agency Regional Mine Development Review Committees (RMDRC). The Victoria-based Reclamation Advisory Committee (RAC) reviews the decisions of the RMDRC and issues the Reclamation Permits which are required before mining can proceed. A major factor in many mine reviews is the consideration of acid rock drainage (ARC) and associated metal release, an issue of particular concern to the Ministry of Energy, Mines and Petroleum Resources, Ministry of Environment, Lands and Parks, and Environment Canada.

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What is ARD?

Acid rock drainage (ARD) is a natural part of our global heritage. It occurs when sulphide minerals in rocks are exposed to the weathering effects of oxygen and water, and results in the chemical change of the sulphur within minerals to sulphuric acid. The acidity in ARD is first generated from the oxidation of sulphide minerals, a process often accelerated by microbiological activity. Acid drainage results when the acidity is entrained by water flowing through areas of sulphide oxidation.

Acid rock drainage results from complex chemical and physical processes, involving a great number of factors. The negative effects associated with acid rock drainage are primarily caused by the impact of dissolved metals released either directly from sulphide minerals or by weathering reactions occurring concurrently with sulphide oxidation. Within the normal pH range of soils and water, the rate of weathering is typically slow and any metals released are relatively immobile.

Under highly acidic conditions, the rate of weathering is much faster, most metals remain soluble and, entrained in runoff and seepage, can have an impact in the receiving environment. Because of the high release rates, even neutralized ARD can contain elevated levels of metals that will have an adverse impact on the receiving environment. These natural effects are enhanced by man-made activities such as highway and logging road construction which frequently expose sulphide-bearing rocks. Acid drainage is associated with mining because many precious and base mineral, and some B.C. coal deposits contain metal sulphide-minerals, and because the mining process breaks the sulphide-bearing rock apart, greatly increasing the surface exposure, and thus the potential for oxidation.

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The leaching of sulphide oxidation products is not however confined to lands disturbed by mining. Low pH values and the characteristic rust-coloured iron staining are often found in natural water courses in the vicinity of undisturbed outcrops of sulphide-bearing rock. The provincial geochemical survey, which has sampled and analyzed streams throughout British Columbia, has found over one hundred occurrences of natural acid generation. Sulphide oxidation and very acidic pH values are also common in marine soils drained for farming in the Fraser Valley and in many other parts of the world.

Nor do all mining operations that expose sulphide-bearing rock create acid rock drainage. For example, ARD will not occur if sulphide minerals are non-reactive. Even if significant sulphide oxidation does occur, ARD will not occur if there is insufficient water to transport the acid weathering products or if pH changes are buffered by a concurrent release of alkalinity from other minerals. Acid neutralization and the precipitation of acid weathering products may occur in the immediate area or as the drainage passes through other more alkaline portions of rock.

While ARD is a natural process, its potential magnitude can be greatly increased by mining. In most undisturbed areas sulphide oxidation is restricted to the thin unconsolidated surface layer and a few small outcrops. In mining, the extraction, cracking and crushing of the sulphide bearing bedrock in underground workings, pits, tailings and rock dumps greatly increases the exposure of rock to oxygen and drainage. The potential for environmental impact is further accentuated at some precious and base metal mines by the abnormally high concentrations of one or more trace elements.

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Acid Rock Drainage at Mine Sites in British Columbia

At mines in British Columbia, as well as in other parts of the world, acid drainage is a major impediment to providing long term environmental protection and returning the mined land to a productive sustainable state. Acid rock drainage is known to occur at seven operating mines and five recently closed mines in British Columbia. Three other operating mines are considered potentially acid generating, as are several proposed mines. Under the current reclamation legislation, all proposed and operating mines with a potential to generate acid rock drainage must develop acceptable plans to minimize ARD to a level that ensures long term environmental protection.

In addition to the presently operating and proposed mines, six mine sites abandoned prior to the enactment of reclamation legislation are known to be acid generating. The regulation of acid rock drainage from historic and operating mine sites is shared by two British Columbia ministries (Environment, Lands and Parks and Energy, Mines and Petroleum Resources) and Environment Canada.

ARD Research

To help the British Columbia mining industry comply with the present comprehensive reclamation requirements, the provincial government is participating in a program of research aimed at developing cost-effective solutions to major environmental problems. A major part of this program focuses on acid rock drainage. As part of this research, the provincial government coordinates and provides funding for the British Columbia Acid Mine Drainage Task Force, and is a vital participant in activities of the national acid drainage program (Mine Environmental Neutral

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Drainage Program - MEND). In 1992, research expenditures for the British Columbia Acid Mine Drainage Task Force amounted to $1.5 million, with funding shared by industry and the provincial and federal governments.

The problems of acid rock drainage will not be solved easily. However, work carried out during the last five years has done much to enhance our knowledge and ability to predict, prevent, control and monitor ARD. The cooperative efforts of the provincial government and the British Columbia mining industry are highly regarded by the rest of Canada, and British Columbia is a world leader in acid rock drainage technology.

The MEMPR Acid Rock Drainage Policy

From previous project reviews and research, the RAC developed a set of working policies and technical initiatives to deal with acid rock drainage. These procedures, rules and guidelines were first complied as a working document (Errington, 1991). A revised working document was released by the RAC as a draft discussion document in July, 1993, both for public information, and industry discussion and comment. In attempting to cover the entire spectrum of ARD issues, the July 1993 Policy document contained sections dealing with exploration, proposed mine developments, prediction, prevention, collection and treatment, commercial leaching, permitting, bonding, monitoring, historic sites exploration, and existing mines. Presently, the RAC is compiling the comments received and forming an expert review group to consider the contentious issues.

In the meantime, a large number of projects are undergoing active development and review, including at least 9 proposed mines and 11 closure plans with ARD concerns. To guide our ongoing review and as a tool for advising proponents, MEMPR have produced this revised set of ARD guidelines, based in part on the July 1993 Policy, with revisions and additions derived from

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recent mine reviews and from comments received from the public and industry. The guidelines set forth in this paper govern the information required from a prediction program, the type of materials used for construction purposes, preventive techniques such as underwater disposal and blending, and inventory and monitoring requirements associated with waste handling. The ARD guidelines set forth herein reflects the RAC's current philosophy of **preventing** ARD generation through prediction and design, avoiding long-term treatment wherever possible.

GENERAL PRINCIPLES

These guidelines are an attempt to provide formal-flexible guidance on ARD, while not limiting the options and approaches. Users are cautioned to consider the specific site and materials, when deciding which and how rules and procedures should apply. At some points, worst-case assumptions are used as the screening criteria for determining whether additional testwork is required. The final criteria used for waste handling and remediation decisions should be based on site-specific test results.

All mining and exploration activity will be regulated in a manner that protects the environment and minimizes the economic risks to the province. To the extent this is technically and economically feasible, ARD works should be compatible with the surrounding land use and should not preclude reclamation of the minesite to its pre-mining productivity.

All potential environmental and social impacts of acid drainage for a proposed mine will be assessed during the Mine Development Assessment Process or its successor, prior to issuance of a Mine Development Certificate.

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The proponent is responsible for development and implementation of an effective ARD program; including all necessary prediction, prevention, and monitoring. Owing to the significant cost and site-specific needs of each mining project, a proponent is advised to discuss the ARD prediction or remediation work with regulatory agencies prior to its implementation.

Because some uncertainty is associated with predicting the occurrence and extent of acid rock drainage, monitoring, treatment and control contingencies may be part of some mine approvals. Prediction is generally more difficult for waste rock dumps, open pits, and underground workings than for tailings impoundments. While the technology is available to prevent the release of acid rock drainage from operating mine sites, it is not yet possible to completely abandon acid-generating mines without requiring long-term programs to collect and treat acid rock drainage or to maintain prevention and control measures.

As a condition of a reclamation permit security bonds will be required to ensure that sufficient funds are available to cover all outstanding reclamation obligations, including long-term costs associated with monitoring, maintenance of preventive structures, and/or treatment of acid rock drainage following mine closure.

ARD and its associated metal leaching is highly site specific. Consequently, the policy and procedures outlined in this document must be tailored to fit the specific mining, geological and environmental conditions of each site.

Acid drainage and metal leaching are ongoing, dynamic processes whose rates and significance are controlled by biological, physical, and chemical thresholds. As a result, ARD studies and remediation programs must consider both the surrounding environment and long term changes in inputs and mitigating processes.

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Through research, B.C. MEMPR will continue to assist the development of improved acid rock drainage technology.

The Province will revise the ARD Policy and regulatory framework to reflect changes in acid rock drainage technology. Modifications and additional requirements for individual mines will be based upon site specific conditions.

PREDICTION OF ACID ROCK DRAINAGE

In order to design a mine which will not result in a major financial liability, a proponent must have a thorough understanding of the nature of all materials exposed during the mining cycle. This information will be required in the development of the extraction, waste handling, and remediation plans.

The proponent is required to predict the acid rock drainage potential (variability and central tendency) for each overburden and rock unit* mined or exposed, and for any waste material, such as waste rock or tailings, created by the operation. The prediction process will consist of the following two phases:

1. Identify and characterize all the rock units, and determine their size, shape, and location.

2. Based on the mining and ARD requirements, create management units from waste type/exposure type/rock units that will be treated alike.

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*Overburden or rock unit: an operational term used to describe one or more types of rock, overburden or waste material that can be handled separately and that have unique properties of significance to ARD.

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The choice of prediction methods will depend on the environment, status of the operation, types of exposed rock and the availability of materials such as drill core. A proponent should focus on the questions critical to their particular waste handling and remediation options. For example, the critical design feature for flooded tailings will be the effectiveness of the water barrier rather than the composition of the ore.

Typical questions asked in ARD prediction include:

- What is the potential for significant trace element release under the different possible geochemical conditions?
- What criteria should be used to distinguish acid drainage generating and non-acid drainage generating material?
- What disposal and remediation methods are needed, and what are the quantity or area requirements?
- What monitoring is required to inform the waste handling operation?
- How long will it take for acid drainage to develop in materials for which there is a delay prior to the application of remedial measures?

The identification of rock units and the creation of management units will typically require an iterative process of sampling, analysis, and classification, similar to that used to determine other geological characteristics such as ore reserves. Based on the results of the first round of sampling and analysis, it may be necessary to further subdivide some of the original rock or management units, or to do additional analysis. Conversely, it may be possible to reduce the number of management units by compiling materials whose difference are not significant with regards to ARD prevention and waste handling.

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Proponents are warned that prediction errors can result from the blind use of technology, incomplete analysis of the test materials, and the erroneous assumptions made in the interpretation of ARD test work. All test assumptions and analyses should be verified for their applicability to the specific site conditions and their usefulness in answering the specific analysis questions.

Sampling and Statistical Requirements

Perhaps the most important phase of the prediction program is sampling. The objective in sampling should be to collect representative samples of all the types of materials that will be exposed. Every sampling program is faced with questions regarding the number of samples, the size of the sample, and the method of sample collection. The answer to each of these questions will of course depend in part on the particular site and materials.

As much of the variability will result from differences in geology, sufficient samples should be taken to accurately characterize the variability and central tendency for critical parameters in each significant rock unit, based on accepted statistical procedures. The number of samples taken from a particular material will depend on its variability and the questions being asked. Where no additional guidance is available, the suggested *minimum* number of samples collected from *each* rock and/or overburden type during *initial* sampling is as follows:

Mass of Each Separate Rock Unit (tonnes)	**Minimum Number of Samples**
<10,000	3
<100,000	8
<1,000,000	26
10,000,000	80

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The sample size should also be based on the prediction question, the variability of the materials, in addition to the proposed modes of extraction, exposure and deposition. Compositing of samples should be avoided unless the geological information indicates it is advisable (e.g., homogeneously disseminated sulphides and carbonate). One exception to this rule is where compositing is done to create more representative test materials. For example, subsamples may be combined to create a sample which matches:

- the minimum possible size for separate extraction (e.g., compositing over a bench or adit height).
- the geochemically functional area or mass that occurs from the mixing that occurs in waste handling (e.g., one lift of a dump).

Once mining is underway, samples can be taken from the actual waste or rock face. Prior to mining, the choice of test materials for predictive work is often restricted to drill core. One advantage in using drill core is that it is available for the entire deposit. Another advantage is that the location and visually detectable geological conditions will have already been recorded, allowing a preliminary separation into "operational" rock types and management units.

It is very important that the geological composition be provided for each sample, to show where the sample fits within the group it is purported to represent. Geological information, which can usually be derived from the drill log, will also be used to reassign samples if the rock units are reclassified, and can be used to explain anomalous ARD test results.

Owing to the significant cost and specific requirements of each mining project, a proponent is advised to discuss the sampling program with regulatory agencies prior to its implementation.

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Requirements of the Prediction Program

The prediction program should incorporate the following procedure:

Step 1. Identify and Characterize Different Materials

Step 1 should consist of three phases. Phase 1 is the initial identification, description and mapping of different rock and overburden types that will (for new mine proposals) or have (for existing or historical mines) been affected by mining. Phase 2 is the separation of geological and geomorphological strata into functionally significant units, and should include determination of their size, shape, and location. Phase 3 is to determine the eventual form of exposure (e.g., pit wall, tailings, or waste rock) for each unit.

The Phase 1 initial description and mapping of different rock and overburden types should be based on general physical and geological properties significant for ARD prediction. The geological description should include consideration of petrology, mineralogy, grain size, texture, structure, fracturing, competency, spatial distribution of the above, as well as any properties such as colour that could be used for identification. Physical properties that should be described include particle size and mode of deposition for unconsolidated materials, and competency or strength for all materials.

The Phase 2 separation of "geologically" different functional units should be based on size and distribution, in addition to differences in geological and physical properties. It is recognized that bedrock and overburden are often both very variable, with two or more types occurring over small distances. Where changes occur irregularly, along continuums, or so often that it is impossible to separate the rock mass into discrete homogeneous units, the proponent should

separate the rock mass into "manageable" units. For example, bench or adit heights may be used to separate separately manageable units of waste rock.

Where new mining projects will affect or be affected by historical mining, or for prediction done on existing operation, Phase 1 should include the characterization of existing mine wastes, underground working, open pits and other mining-related disturbance. The characterization of existing mine workings should include the particle size distribution, mode of deposition and/or exposure, and the quantity (weight, volume, and aerial extent). Existing mining-related disturbance should be included on the overburden map produced in Phase 2. The map created should be of sufficient detail and quality to clearly show the topography of both the mined areas and the surrounding terrain, and the location of any permanent or intermittent water courses. Historical mining occurring in the same watershed should also be included.

While often overlooked in the rush to do less complicated ARD-specific testing, step 1 is necessary to ensure that the entire range of geological variability is addressed and that the ARD test work is comprehensive. The geological and physical properties used to separate different rock and management units will often strongly effect site specific ARD criteria.

Step 2. Initial Screening

Conduct initial screening of materials based on the sulphide content, available metal content, and pH value. Materials with a paste pH less than 3.5 will be considered a potential source of acid drainage. All materials with either more than 0.3% sulphide-S or a pH less than 5.0 should be tested further.

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The form and amount of readily soluble constituents should be measured in materials that are already oxidized to identify situations where there is a potential for the dissolution of residual weathering products. The method for determining availability should be selected according to site-specific criteria.

For projects where the geology indicates there will be sulphides present, a proponent is advised to combine steps 2 and 3.

Step 3. Acid Base Accounting

The next phase of the ARD test work is to measure the maximum acid generation potential (AP) and maximum neutralizing potential (NP) of each rock and overburden type, and to use traditional acid base accounting procedures to calculate the net neutralization potential (NNP) and neutralization potential ratio (NPR).

Acid base accounting is the primary screening tool used to determine whether further site specific ARD testwork is required. The screening criteria used to evaluate a need for further testwork based on acid base accounting tests are:

- Materials with sulphide minerals whose net neutralizing potential (NNP=NP-AP) is negative are likely to be a acid drainage source. Exceptions are possible if the sulphide content is very low and/or there are significant slow release, non-carbonate sources of alkalinity.
- The acid drainage potential will be considered uncertain if materials have a ratio of neutralization potential to potential acidity (NP:AP) of less than 4:1.

The ratio of 4:1 represents the worst case to date and was selected to ensure the detection of sites where there is an unfavorable balance between long-term acid generation and neutralization reactions or where the composition of a waste rock's fine-sized fraction varies significantly from that of the whole rock. It is recognized that a 4:1 ratio is conservative and will be higher than the actual composition of acid drainage generating materials at most sites.

Where the acid rock drainage potential of a waste material or geological unit is uncertain, it will be considered acid drainage generating until the proponent can show through further testing (step 4) that the acid and neutralization reaction rates are favorably balanced.

It is cautioned that acid base accounting provides only a rough assessment of the potential for acid drainage. More refined site and material-specific interpretation or testing should be used if less conservative, more accurate information is required.

Step 4. Determine Site and Material Specific Prediction Criteria

To predict the ARD potential and to address the prediction questions listed previously, the proponent is required to develop site and material-specific criteria based on the relative rates of acid generation and neutralization reactions, and the size of the reactive fraction. The data used may be obtained from a variety of sources, including a more detailed characterization of the material, comparisons with similar materials at other sites, weathering and leachate quality observed in soils and outcrops, the quality of seepage from existing waste materials, kinetic laboratory tests, and field trials.

Often there is no one piece of evidence or conclusive test, and the proponent must combine information from a variety of sources. For example, experience at other sites might be presented

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in combination with detailed geological data showing that the rock or waste types are very similar.

Kinetic tests are often used to estimate relative acidity-neutralization reaction rates and to predict metal release and loading. The value of kinetic tests as a predictive tool will be greatly enhanced where it is shown that these tests simulate either the real field release rates or the actual balance of important processes, such as oxidation, dissolution, and entrainment. A geological description should be provided for the kinetic test material to show how each sample fits within the rock or management unit it is supposed to represent.

Valuable field evidence may be obtained from trends in the relative elemental ratios of seepage water, and from the relative weathering rates and fine particle replenishment observed in old wastes or similar natural soils. If the materials can be matched to the new mine wastes, field evidence is a very good prognostic tool.

Depending on the materials and site, it may be necessary to determine the neutralizing potential of non-titratable, slow release minerals, or the size and rate of additions from biotic and climatic sources.

Although universal ABA rules may not apply, ABA characteristics can often be the best criteria to use for distinguishing materials.

Often overlooked in the desire to do simpler ARD-specific tests, detailed geological characterization is usually necessary if one is to predict how materials will perform. Where there is a potential for the generation of acid drainage or metal release through weathering or dissolution, the proponent should determine the range, variability, and central tendencies for the following properties:

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- Mineralogy and associated elemental composition
- Readily soluble constituents
- Sulphide types (amount, reactivity, and spatial distribution)
- Carbonate types (amount, reactivity, and spatial distribution)
- Mineralogical and rock fabric characteristics that will influence weathering.

The properties listed above may be modified to match the specific conditions of each site, material and disposal option.

In addition, and in many cases in preference, to doing whole rock analysis, the proponent should estimate the composition of the fine-sized fraction and the surfaces of coarse particles. For proposed operations which do not yet have wastes to analyze, comminution effects may be predicted from the geological characteristics of the rock and weathering simulation methods, such as grinding and slaking.

PREVENTION OF ACID ROCK DRAINAGE

All mines with a potential for acid drainage must provide operational reclamation and abandonment plans showing how they will reduce the generation of acid drainage to levels not exceeding receiving water quality objectives, both in the short and long term. In cases where the

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success of prevention measures cannot be assured, an assessment of the potential for failure and of the possible impacts will be required. Detailed contingency plans to reduce the risk to the environment will also be needed. This will usually consist of plans for a collection and treatment system.

Until it is determined that there is no potential for acid drainage or other water quality problems, material with one or more of the following properties shall not be used for roads, dams or other construction purposes:

- A total sulphide-S level greater than 0.3%
- A paste pH less than 5
- A potential for significant metal loss from residual weathering products.

Underwater Disposal

Underwater disposal of tailings or waste rock in secure manmade structures is currently an acceptable form of acid rock drainage prevention. Underwater disposal in natural water bodies will only be considered where there is shown to be no significant impact on water quality, fisheries*, recreation, or downstream flow, and where the water bodies are shown to be the most environmentally suitable disposal site.

Further research is required to assess the impact of the underwater disposal of tailings or waste rock in biologically or water-quality-sensitive lakes before this disposal alternative will be considered.

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*In the case of disposal into natural water bodies, appropriate approval would have to be obtained from federal authorities under the Fisheries Act.

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In cases where underwater disposal of tailings or waste rock is proposed, the proponent must show that:

- The mine wastes do not contain significant readily soluble deleterious substances.
- The water balance ensures that all potentially acid-generating wastes will be continuously covered by water.
- There will be no significant impact as a result of wave action, ice, drought, flooding, avalanches, earthquakes, thermal overturn, surface and groundwater movement, and other relevant natural factors.
- The mode of deposition, the water depth and other design features satisfy the requirement for long-term prevention of acid drainage.

Manmade impoundments shall be designed and maintained for long-term geotechnical stability, taking into account the possible effects of biological activity, seismic and extreme meteorological conditions.

A water cover is currently an acceptable form of acid rock drainage prevention for underground workings or open pits. Where only partial flooding can be achieved, the proponent must predict both the extent of flooding and water quality impacts from unflooded mine walls.

The timing and inflow rate requirements in flooding open pits and underground workings will be based on the hydrologic conditions, the relative reaction rates of acid generation versus neutralization, and the potential release of acid products. Proponents must demonstrate that any water released to the environment will be of acceptable quality. Hydraulic bulkheads or material barriers in underground workings shall be designed to allow ongoing verification of the water level and of geotechnical stability.

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Blending

Blending of acid generating and acid consuming materials to create an overall acid consuming material is an acceptable acid rock drainage prevention strategy. The proponent will be required to show that there is sufficient information about the materials and sufficient neutralizing capability to ensure that blending can be carried out successfully. Given the potential for incomplete mixing, more conservative NNP and NPR criteria will likely be required than those set for single homogeneous materials (see earlier discussion of acid rock drainage prediction).

The proponent will also be required to demonstrate that the blending plan is compatible with the mine plan, that it is possible to achieve the required control in materials handling and that there is sufficient disposal capacity. This should include any interim prevention measures required for the protection of exposed material stockpiled prior to final disposal.

At permitting, the proponent will be required to itemize the sample type and size, sampling frequency, the list of analyses, proposed QA/QC and processes for communicating monitoring results to the blending operation. In addition to the analysis of source materials, monitoring will also be required to verify the composition of the resulting blend.

COLLECTION AND TREATMENT OF ACID ROCK DRAINAGE

Although prevention will be the primary method of acid rock drainage control for new mines, collection and treatment may be accepted as a mitigation method if the proponent can demonstrate that -

- All preventative methods have been examined and are determined to be technically and economically unfeasible with current technology

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- The risk (likelihood of occurrence and consequences) to the environment caused by a failure to the system is acceptable
- The quantity of acid rock drainage is readily manageable
- Treatment sludge can be disposed of safely.

In addition, the proponent must provide adequate security to finance long-term collection and treatment.

Where collection and treatment is proposed as the principal means of protection, the proponent must show that the system can be maintained in perpetuity. The supportive evidence should include detailed engineering and economic analysis, including consideration of relevant biological factors, and a comprehensive risk analysis to show that environmental values will not be jeopardized. Any proposed collection and treatment system should include adequate resources to support its operation.

While treatment technology is generally effective, long-term collection and treatment is among the most expensive remediation options. Because of the long time frame and uncertainties about future costs, government's bonding requirements are likely to make collection and treatment an unattractive option for new mines. Since final site reclamation is not possible and there are ongoing sludge disposal problems, proponents must recognize that the use of collection and treatment as a primary means of control will only be approved after consideration of the land use, environmental and socio-economic impacts and benefits. Approval of such programs will be at the discretion of review agencies.

During the mine operation all collection ditches, dikes, impoundments, and pumping systems must be designed to handle a one-in-200-year flood during the mine operation. For

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abandonment, the minimum design criteria for structures whose failure would jeopardize the effectiveness of the acid rock drainage prevention plan should be based on the consequence of failure. Where the consequences of failure are high, the minimum design criteria should be the probable maximum flood (PMF) and the maximum credible earthquake (MCE).

RECLAMATION PERMITTING

Following a detailed review under the Mine Development Assessment Process, mines are regulated under mine plan approvals, reclamation permits, and waste and water management approvals, permits, and licenses. All of these approvals, permits, and licenses are issued subject to

monitoring and confirmation of predictions, and with conditions to prevent the generation and dispersal of acid rock drainage.

BONDING

As a condition of a reclamation permit, a security will be required to ensure that sufficient funding is available to cover all outstanding reclamation obligations, including long-term costs associated with the necessary monitoring, maintenance, collection, and treatment of acid rock drainage following mine closure.

Bonding requirements will be addressed at each stage of the Mine Development Assessment Process. The Regional Mine Development Review Committee, following a detailed technical review, will recommend an appropriate level of security to be required as a condition of the reclamation permit. The level of security will increase as reclamation obligations increase during mine operation. The security will be set at a level that will, in a self-perpetuating manner, pay for:

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- the long-term inspection, monitoring, and maintenance, and if necessary the operation of collection, containment, and treatment plant facilities
- the long-term inspection, monitoring, and maintenance of preventive and control structures.

The security will take into account the high degree of uncertainty in predicting these costs. Securities attached to existing mines will be increased should acid rock drainage be discovered. Should remediation or prediction work reduce the extent of acid generation or the risk of future acid generation, security levels will be reduced.

MONITORING

Monitoring programs designed for environmental protection and for the early detection of acid rock drainage will be required as a condition of permits issued by the Ministries of Energy, Mines and Petroleum Resources and Environment, Lands and Parks. Intermittently, QA/QC programs should be carried out to verify the accuracy and precision of the data.

During mine operation, companies will be required to maintain a detailed inventory for all waste or exposed materials. This information should be continually updated and readily accessible in a complete package, including analysis results for drill core, waste materials, exposed surfaces, and water draining from various wastes and off site. The ARD information should include the rock or overburden type, acid/base accounting data, mineralogical and elemental composition, storage location, and date of emplacement. pH and readily soluble constituents should be measured where some weathering has already occurred.

Following mine closure, the permittee will be required to undertake all long-term requirements including monitoring, inspecting, reporting on, and maintaining the mine site and ancillary ARD

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facilities. Monitoring programs will be designed to ensure that operational procedures are being carried out and to determine if prevention techniques have been successful.

ANNUAL REPORTS

Annual reports summarizing the materials, methods, and results of the acid rock drainage monitoring program will be required as a condition of all reclamation permits. The annual reports should also summarize the previous year's mining and waste disposal, the materials mined and any anticipated changes to the mine plan. Cumulative detailed ARD monitoring records should be appended.

HISTORIC SITES WITH ACID ROCK DRAINAGE

Under the **Mines Act**, the responsibility for containing acid rock drainage from historic mining operations currently rests with the "owner" of the mineral rights, whether or not this owner caused the problem. The Ministry of Environment, Lands and Parks, under the **Waste Management Act,** may assign responsibility to past and current owners.

The Ministry of Energy, Mines and Petroleum Resources recognizes that, in many cases, the most efficient and effective method of eliminating acid rock drainage from historic mine properties is to recommence mining using modern mining and environmental control practices. Consequently, the Ministry believes the regulatory policy should encourage active exploration and development when considering the liability of the present or prospective owner.

The Ministry of Energy, Mines and Petroleum Resources, in cooperation with the Ministry of Environment, Lands and Parks, is committed to establishing a registry of mines and

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exploration properties with an existing acid rock drainage problem, as well as sites where a potential for acid rock drainage exists. To date, nine historic minesites have ARD concerns.

EXISTING MINES WITH ACID ROCK DRAINAGE

There are five recently closed and seven operating mines that currently are known to be producing acid rock drainage. Four recently closed and three operating mines have an uncertain ARD status.

All operating and recently closed mines are required to submit, or have already submitted, detailed closure plans.

Reclamation bonds are being reviewed to ensure that sufficient funding is available to pay for the abatement of acid rock drainage, including, where necessary, the costs of long term collection, treatment and monitoring.

COMMERCIAL LEACHING

Commercial leaching with acidic solutions can provide a cost effective means of recovering copper, which maximizes the utilization of the provinces mineral reserves.

Commercial leaching operations may only be approved where they are designed and constructed to ensure adequate environment safeguards and where sufficient bonding is in place to adequately secure the necessary long term prevention, control, collection and treatment of acid rock drainage. Assuming it is required, all the guidelines for collection and treatment should also apply to commercial leaching.

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Similar to the case for the collection and treatment of incidental acid rock drainage, the proponent of a commercial leaching operation must provide detailed engineering and economic analysis to demonstrate that acid drainage collection, containment and treatment can be maintained in perpetuity. Commercial leaching operations by their nature result in the production and processing of high strength acid rock drainage. As such, the level of detail for environmental and engineering analysis will be higher than that required for most mine operations. Small scale field pilot studies may be required to demonstrate that these facilities can be operated safely. The proponent must also provide a comprehensive risk analysis that considers adjacent land use and shows that environmental values will not be jeopardized. Because the risk is strongly affected by the proximity of environmental resources, siting of such facilities is critical.

EXPLORATION

The Ministry of Energy, Mines and Petroleum Resources will ensure that all exploration activity is regulated in a manner which limits the risk of acid rock drainage.

Companies engaged in exploration activities for coal and mineral resources are required to submit their proposed programs to the Ministry of Energy, Mines and Petroleum Resources for approval. These proposals are referred to all pertinent government agencies for review. A reclamation permit is required for all mechanical exploration, and a reclamation security or bond is required prior to issuance of this permit.

Previous guidelines for prediction (page 9) apply to exploration activities resulting in sufficient rock disturbance to create a potential for ARD. A general rule of thumb is that exposure of a hundred tonnes of rock constitutes significant disturbance. The exact

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amount will depend on both the environment and the type of rock. Examples of these types of activities included the construction of an exploration adit or the removal of a bulk sample.

Significant rock disturbance does not generally occur and thus ARD work will not be required in exploration activities such as drilling, surface trenching and soil sampling. The necessity for having proponents consider ARD during exploration and development is supported by the strong ARD generation and metal release observed for waste rock extracted from exploration adits at a number of pre-mining developments. For exploration to be an accepted, temporary land use, compatible with surrounding land uses, prospectors must take the necessary provision to ensure that ARD and consequent metal release does not compromise productivity and water quality standards.

Where exploration includes underground activities or significant surface rock disturbance, applicants are required to determine the theoretical acid generating potential for all rock units encountered.

The reclamation permit conditions for any exploration activity with a potential for creating acid rock drainage are set by the Regional Mine Development Review Committee. Where a theoretical potential for acid generation is indicated, the proponent must present plans to prevent the release of acid rock drainage. In cases where the success of prevention measures cannot be assured, the security required will reflect the cost of long term acid rock drainage control, and will take into account the risk to the environment. Where a potential for acid rock drainage is identified, more detailed site and receiving water monitoring may be required to determine what, if any, environmental impacts may occur. If the environmental risk and consequences are too great, the Committee may recommend that the permit application be rejected.

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COMMITMENT TO TECHNICAL SOLUTIONS

The RAC is committed to incorporating new technology into mine design and closure plans, and updating this ARD policy as this technology becomes available.

The provincial and federal governments have demonstrated their commitment to technical solutions through support of the British Columbia Acid Mine Drainage Task Force and the Mine Environment Neutral Drainage (MEND) programs, updates of the Acid Rock Drainage Technical Guide and the creation of the U.B.C. Chair on Mining and the Environment.

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ENVIRONMENTAL MANAGEMENT FOR MINING
CANADIAN LAND RECLAMATION ASSOCIATION
20TH ANNUAL MEETING
SASKATOON, SASKATCHEWAN

OVERVIEW OF RECLAMATION AND CLOSURE REQUIREMENTS FOR CANADIAN MINES

Sheila Daniel M.Sc.
Kilborn Inc. , 2200 Lakeshore Blvd. W.
Toronto Ontario
M5W 1A8

Terry Walbaum, P.Eng.
Kilborn Western Inc., 357 Third Ave.
Saskatoon Saskatchewan
S7K 1M6

OVERVIEW OF RECLAMATION AND CLOSURE REQUIREMENTS FOR CANADIAN MINES

Sheila Daniel M.Sc., Kilborn Inc. and Terry Walbaum P.Eng., Kilborn Western Inc.

Abstract

Reclamation activity in the mining industry has increased across Canada as more mines reach the end of their life, and progressive rehabilitation becomes part of day-to-day operations. Reclamation planning often starts even earlier, during the prefeasibility and feasibility stages of a project when conceptual plans are developed and design alternatives reviewed. Kilborn conducted this review of reclamation and closure requirements in order to assist property managers with a preliminary assessment of their reclamation planning responsibilities.

In general, planning and implementation of reclamation at Canadian mine sites is under the authority of provincial or territorial agencies. Most of the provinces have already developed, or are currently preparing, reclamation guidelines, enabling legislation, and overall requirements for closure. Reclamation requirements are generally formalized through the mine planning or permitting process prior to development, although existing mines are also required to comply according to a negotiated or set schedule.

On completion of the planning process, an agreed upon level of financial assurance or security is often required to support final reclamation should the owner either physically or financially abandon the site, and the environmental liability revert to the Crown. This requirement is often significant, and must be assessed when determining the feasiblity of a new project, or in the review of environmental liabilities associated with the sale and transfer of an existing operation.

Introduction

Mining may alter considerably the physical and chemical characteristics of a site. Canada and other countries around the world have developed reclamation policies in order to ensure that environmental standards are met during operation and at final reclamation, and that an acceptable end-use can be obtained. For a new operation closure planning is generally considered at the same time as project design; usually during the prefeasibility and feasibility stages of a project. A key element of the planning process in Canada is the development of a reclamation or closure plan that describes actions to be taken during operation and at closure to return the site to an approved end-use. This use is determined by the proponent in consultation with the lead agency on review of site conditions.

This paper provides an overview of current reclamation plan requirements for metal mines in each of the provinces and territories. For provinces where reclamation is addressed primarily within the Environmental Assessment process, only a limited discussion is presented. Other types of mining such as coal, potash and industrial minerals have generally not been addressed since there appears to be limited consistency in their treatment across Canada.

Readers should refer to documents listed by province or territory at the end of the paper, and enabling legislation or applicable regulations for further details. Since reclamation related legislation and regulations are being continuously updated, current information should be sought from the lead ministry listed in Table 1.

British Columbia

Reclamation planning is an integral part of all stages of the Mine Development Assessment process in British Columbia, but is of particular interest during the final permitting stage. All operators must apply for and receive a Reclamation Permit prior to the initiation of mine work from the Chief Inspector of Energy, Mines and Petroleum Resources.

The application for a Mine Development Certificate must include a detailed conceptual reclamation and mine closure plan describing:

- existing environmental conditions;
- proposed mining program;
- proposed reclamation and research program for first five years of mine life;
- conceptual closure plan;
- monitoring program during closure; and,
- estimate of reclamation costs.

Reclamation Permits are generally issued for a period of five years, at which time the permit and proposed reclamation activities are reviewed. The closure plan should address in detail the first five year period of mining and reclamation programs. Annual reports are required in order that concurrence with the plan and the success of the on-going programs can be evaluated.

A financial security deposit is required in an amount based on the costs and risks associated with the development for the taxpayers of the province. The security is set to reflect the total projected costs for any reclamation, treatment and monitoring costs, and is based on the cost estimate provided by the proponent in the reclamation plan.

Alberta

The focus for reclamation in Alberta has been placed on coal mines and tar sands operations, since metallic minerals are generally not mined. Prior to any surface disturbance the proponent must obtain a Development and Reclamation Approval. A reclamation plan is required which outlines the means by which the company will fulfill Alberta's reclamation requirements (return of equivalent land capability). A security deposit is required which will address the estimated cost for reclamation.

Saskatchewan

All new metal mines must be reviewed through the Saskatchewan Environmental Assessment process. The Environmental Assessment process is currently under review and may be changed to include specific regulations. Reclamation planning is an important component of the Environmental Impact Statement, which forms the basis for environmental approval for the project. Reclamation must be addressed at a conceptual level within the Project Proposal, and in greater detail within the Environmental Impact Statement if deemed to be required.

Manitoba

Under the 1992 *Mines and Minerals Act*, all new mines are required to develop a closure plan and provide financial security in accordance with the applicable regulations. Although required by the Act, guiding Regulations are not available, and as a result, reclamation planning at this time is addressed solely within the Environmental Assessment process. Mine reclamation regulations are currently being drafted and are expected to be approved in 1996. The Environmental Assessment process currently used does not have a means of requiring a financial security for reclamation.

Ontario

Ontario is generally considered to have one of the most comprehensive closure planning process in Canada. All new projects, existing mines (operating and non-operating), selected advanced exploration projects and other operations designated by the Director of Mine Rehabilitation, are required to prepare a closure plan. After the regulations came into force (1991), existing mines were provided with a schedule for submission of their plan, while new operations were not allowed to begin mining without having an approved closure plan in place. Several existing operations are in this intervening stage and have yet to submit a closure plan to the government.

A guide is available to assist proponents in closure plan organization and content. For new mines, the plan must address:

- pre-development environmental conditions;
- proposed undertaking;
- proposed reclamation measures;
- impacts the project will have on the environment after completion of all reclamation activity;
- detailed reclamation schedule;
- proposed monitoring and management programs; and,
- detailed cost evaluation.

The cost evaluation may be submitted under a separate cover since it forms the basis for the financial assurance. Financial assurances are generally in the form of: cash; letter of credit from a Bank (as per Schedule A of the *Bank Act*); a bond of a guarantee company approved under the *Guarantee Companies Securities Act*; although on approval of the Director other forms may be accepted. The evaluation must address on-going reclamation costs, final reclamation, and costs associated with annual reporting and monitoring of reclamation activities.

Quebec

New provisions were added to the *Mining Act* on March 9, 1995 which require all holders of mining rights and mining operators to restore affected areas to an approved state. As part of these provisions, reclamation plans are required by the Ministère des Réssources Naturelles (MRN) for all new and existing mines in the province. Existing mines must submit reclamation plans prior to March 9, 1996.

The reclamation plan must include descriptions of the following information:

- site characteristics;
- reclamation activities to be completed on cessation of mining;
- progressive rehabilitation to be undertaken during mining;

- reclamation schedule for all phases;
- assessment of costs for all reclamation work; and,
- the form of financial guarantee.

Updating of the plan is required every five years, or more often if so designated. This allows the plan to be revisited to reflect new technologies or changing site conditions.

A guarantee must be provided in an amount of 70% of the estimated reclamation costs for all impacted areas for most mines. If mining will be completed prior to March 9 1997, a guarantee of only 15% of the estimated cost is required. If the mine life is expected to be five years or less, an initial payment is required within 15 days of approval.

The guarantee may in the following forms:
- a cheque;
- government bonds;
- guaranteed investment certificate;
- letter of credit;
- security or guarantee policy issued on behalf of the government;
- immovable hypothec provided by a third party; or,
- a trust.

The amount of financial guarantee required may be reassessed during operation on successful completion of progressive reclamation work, or if more economical methods of reclamation are developed. Otherwise, the guarantee is held until a Certificate of Release is issued. The amount guaranteeing the rehabilitation of mining sites are tax deductible.

New Brunswick

Reclamation planning is an important part of the New Brunswick mine approval process for all new mines, and must be addressed within the feasibility study which supports the mining lease application. A reclamation plan must be approved and financial assurance received prior to issuing of a mining lease.

The reclamation plan should describe the existing environment and the potential for environmental impacts and proposed mining and milling operations. The proponent is guided through reclamation plan development by a technical committee representing the agencies which will eventually review and approve the program. While New Brunswick has required reclamation plans since the Regulations were approved in 1986, like other provinces with older legislation, the level of detail required by the technical committee in the plans has increased substantially.

The reclamation plan is supported by a requirement for financial security. The amount of security may be determined according to the following schedule: $10,000 plus an additional, $1,500/ha of Crown Lands disturbed; and $3,000/ha of disturbed private lands. Area disturbed is determined by the Minister based on the reclamation plan. These funds are recognized as being insufficient to reclaim an acid generating mine site. Additional amounts of security may be required by the Minister if deemed necessary to support reclamation.

The security can be in the form of: money, a negotiable bond, irrevocable documentary credit, or a bond of an insurance company. This security is maintained until deemed to be no longer required.

Nova Scotia
As in New Brunswick, reclamation is considered at the mine permitting stage in Nova Scotia. A general reclamation plan is required in the application for a mining permit outlining the general objectives of reclamation and means by which they will be achieved. A description of the post-operation environmental monitoring program is also required.

No reclamation guidelines or standards are available to proponents from the Province of Nova Scotia. Reference is generally made to Tables 5.1 to 5.8 in Mine Reclamation in the Northwest Territories and Yukon (Indian and Northern Affairs Canada, 1992).

A reclamation security deposit is required in an amount dependant on the maximum disturbed area during the mine life, and should represent the real cost of reclamation to the extent possible. Proponents have the option of either independently preparing a reclamation cost estimate and having it approved by the Province, or allowing the Ministry of Natural Resources to assess the amount of financial security required. The bond may be in cash, a letter of credit, assurity bond, or some other negotiated form. The amount of the bond may be adjusted every two years by the Director of Mines to address increased environmental liability or completion of progressive rehabilitation.

Newfoundland
Newfoundland does not have specific reclamation legislation, however, reclamation planning is an important component of the Environmental Assessment process. Reclamation must be addressed in the registration document and the Environmental Impact Statement, should it be required. Once the project is approved, the Province has the option of attaching site-specific reclamation requirements to the mining lease. Reclamation standards are generally flexible and are negotiated by representatives of applicable Provincial and Federal agencies with the proponent.

There is no vehicle currently available to affix a financial assurance for reclamation to the approval of a new mine. Should reclamation activities be deemed unsatisfactory, the Province has the option of refusing to cancel the lease on the property on cessation of activity. Liability for the property would remain with the proponent until such time as reclamation has been completed to a satisfactory level.

Northwest Territories and Yukon Territories
Neither territory has specific reclamation guidelines for new or existing mines, although several documents are available outlining mine reclamation practices and standards for northern sites as outlined at the end of this paper. The Yukon Territory is currently developing reclamation guidelines which are expected to be completed before the end of 1995. A Proposal for Discussion titled, 'The Regulation of Mine Site Reclamation for Quartz Mining in Yukon' was published in 1993.

Two primary means are available by which reclamation planning is conducted in the territories: within the Environmental Assessment process as required by the *Canadian Environmental*

Assessment Act; and as part of the application for a Water Licence in the mine permitting process. Reclamation is addressed on a conceptual level within the Environmental Assessment. The water licence application requires a description of the reclamation methods and standards proposed, and acts as the reclamation plan for the property.

As a condition of the Water Licence, a proponent may be required to post financial assurance in an amount equivalent to the cost of proposed reclamation activities.

Conclusions

A comparison of some of the requirements by province or territory is contained in Table 1. Several of the provinces have reclamation guidelines in preparation, and as a result additional changes over the next several years are expected. While no two provinces or territories address mine reclamation planning the same way, all agencies contacted are cognizant of the importance of early reclamation planning, whether during the prefeasibility, feasibility or permitting stage of the project. An assessment of reclamation requirements near the end of mine life is no longer acceptable, and progressive reclamation is preferred wherever possible.

It is expected that the requirement for detailed reclamation planning and documentation will increase over the next few years, including a requirement for annual reclamation reports. Updating of the reclamation security deposit at set intervals is anticipated to become more prevalent. The main reclamation issue which has not been clearly addressed is the tax treatment of financial security deposits.

Table 1: Reclamation Planning Requirements for Metal Mines in Canada

	British Columbia	Saskatchewan	Manitoba	Ontario	Quebec
Reclamation Plan Document	required	not required	not required	required	required
Reclamation Planning	-	in EA process	in EA process	-	-
Enabling Legislation	Mines Act	Environmental Assessment Act	Environment Act	Mining Act	Loi sure les mines
Lead Agency	Ministry of Energy, Mines and Petroleum Resources	Environment and Resource Management	Ministry of Environment	Ministry of Northern Development and Mines	Ministère des Réssources Naturelles
Guidelines or Standards	available	available	not available	available	available
Evaluation of Costs	required - developed by proponent	not required	not required	required - developed by proponent	required - developed by proponent
Financial Assurance	required	not required	not required	required	required

	New Brunswick	Nova Scotia	Newfoundland	Northwest Territories	Yukon Territory
Reclamation Plan Document	required	not required	not required	not required	not required
Reclamation Planning	-	required	required	required	required
Enabling Legislation	Mining Act	Environmental Assessment Act	Environmental Assessment Act	Canadian Environmental Assessment Act	Canadian Environmental Assessment Act
Lead Agency	Ministry of Natural Resources	Ministry of Natural Resources	Ministry of Environment	NWT Waterboard	Yukon Waterboard
Guidelines or Standards	not available	not available, NWT used	not available	available	available
Evaluation of Costs	required - developed by proponent	required - developed by proponent or by agencies	not required	may be required	may be required
Financial Assurance	required	required	not required	not strictly required	not strictly required

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PRE-DEVELOPMENT PLANNING FOR THE DECOMMISSIONING OF SMALL OPEN-PIT URANIUM DEPOSITS AT THE RABBIT LAKE OPERATION

L.W. Adrian and J.P. Jarrell
Cameco Corporation
2121 - 11th Street West
Saskatoon, Saskatchewan
S7M 1J3

PRE-DEVELOPMENT PLANNING FOR THE DECOMMISSIONING OF SMALL OPEN-PIT URANIUM DEPOSITS AT THE RABBIT LAKE OPERATION

L.W. Adrian[1] and J.P. Jarrell

Abstract

It is now generally recognized that rock with sub-economic levels of uranium mineralization has the potential to generate long-term environmental problems which require improved management techniques. The presence of nickel and arsenic in uranium ore deposits can exacerbate the problem.

In planning the development of the Collins Bay A-zone and D-zone ore bodies at Rabbit Lake, Cameco has employed some new methods for developing waste rock management plans, designed to prevent future problems rather than having to react to them after mining has been completed.

The two ore zones were drilled a second time, with the emphasis on the assessment of the quality of the waste rock around the ore. Fifty-seven holes were completed. The core was logged for contaminants, in particular nickel and arsenic, as well as low-grade uranium, which had not been an issue when the ore bodies were initially identified. Chemical analyses were performed for arsenic, nickel, sulphur and uranium in the waste rock halo around the ore bodies. Acid-base accounting, shake-flask tests, and humidity cell and saturated column tests were performed to predict leaching properties of the various constituents under both dry (oxidizing) and flooded conditions. The SERMINE block model was then used to calculate the volumes of each rock type expected to be mined.

The regulatory requirement to model post-decommissioning radioactivity impact gave us the tools which could be used to model the long-term impacts for other non-radioactive elements. Probabilistic assessment of decommissioning alternatives was done by adapting a version of the Uranium Tailings Assessment Program (UTAP). These data, when coupled with experience gained in mining the larger but similar B-zone deposit, enabled us to develop a practical waste rock management plan, balancing costs to segregate waste rock on the basis of its anticipated long-term environmental performance against the future cost to manage an unsegregated waste rock pile. This approach will satisfy environmental concerns while allowing economic development to proceed.

Project Background

Cameco Corporation is currently in the process of developing two relatively small uranium ore deposits at the Rabbit Lake Operation in northern Saskatchewan. As shown in Figures 1 and 2, these deposits are located on the eastern boundary of the Athabaska formation, a geological area with a large number of world-class uranium ore deposits. The A- and D-zone deposits are

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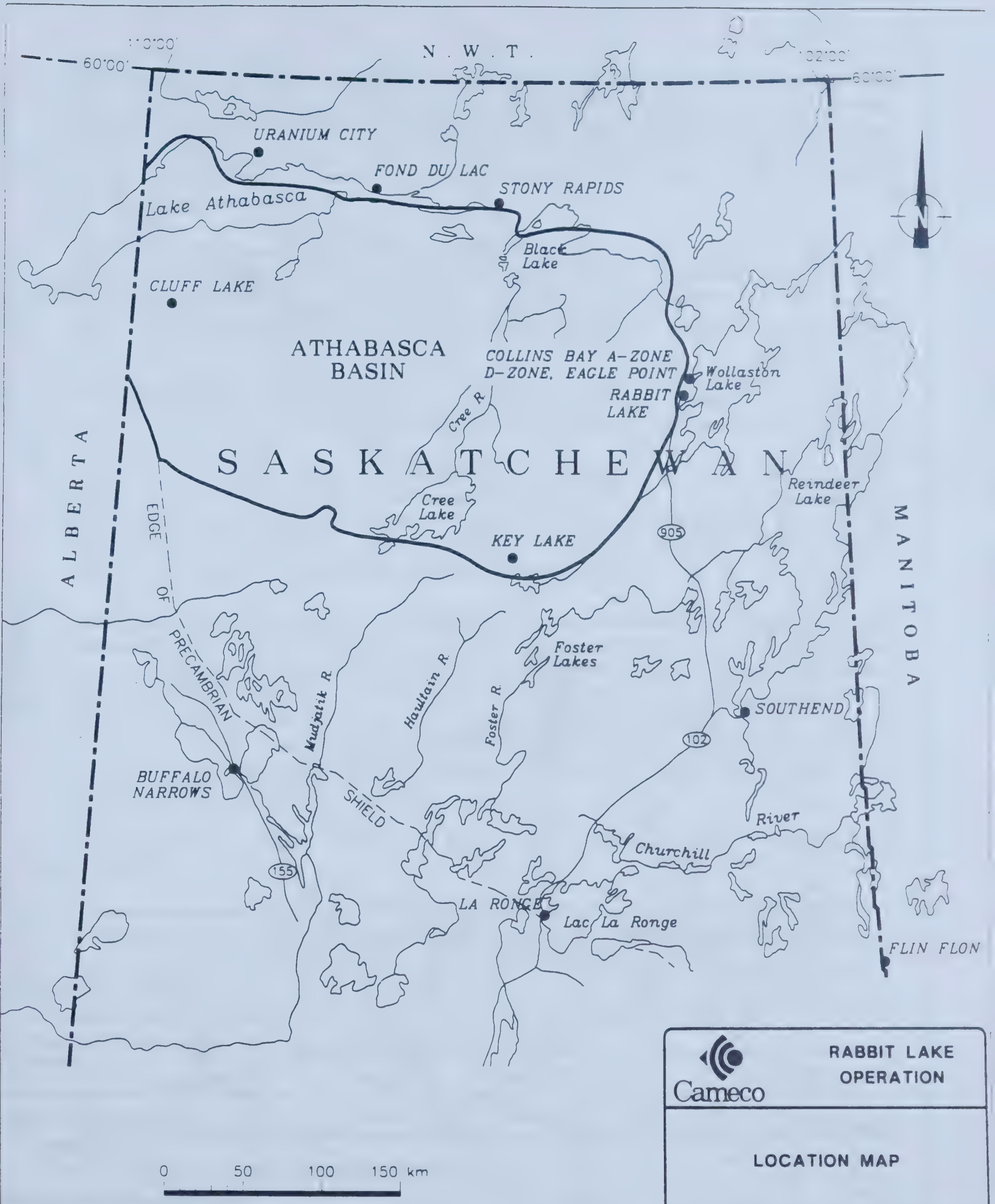
[1] Currently with Cameco's subsidiary Kumtor Operating Company.


N.W.T.
110°00'
60°00'
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URANIUM CITY
FOND DU LAC
STONY RAPIDS
Lake Athabasca
Black Lake
CLUFF LAKE
ATHABASCA BASIN
COLLINS BAY A-ZONE
D-ZONE, EAGLE POINT
Wollaston Lake
RABBIT LAKE
Cree R.
SASKATCHEWAN
ALBERTA
MANITOBA
Reindeer Lake
Cree Lake
KEY LAKE
905
EDGE OF PRECAMBRIAN SHIELD
Foster Lakes
Haultain R.
Mudjatik R.
Foster R.
SOUTHEND
102
BUFFALO NARROWS
Churchill River
155
LA RONGE
Lac La Ronge
FLIN FLON
N
0 50 100 150 km

Cameco

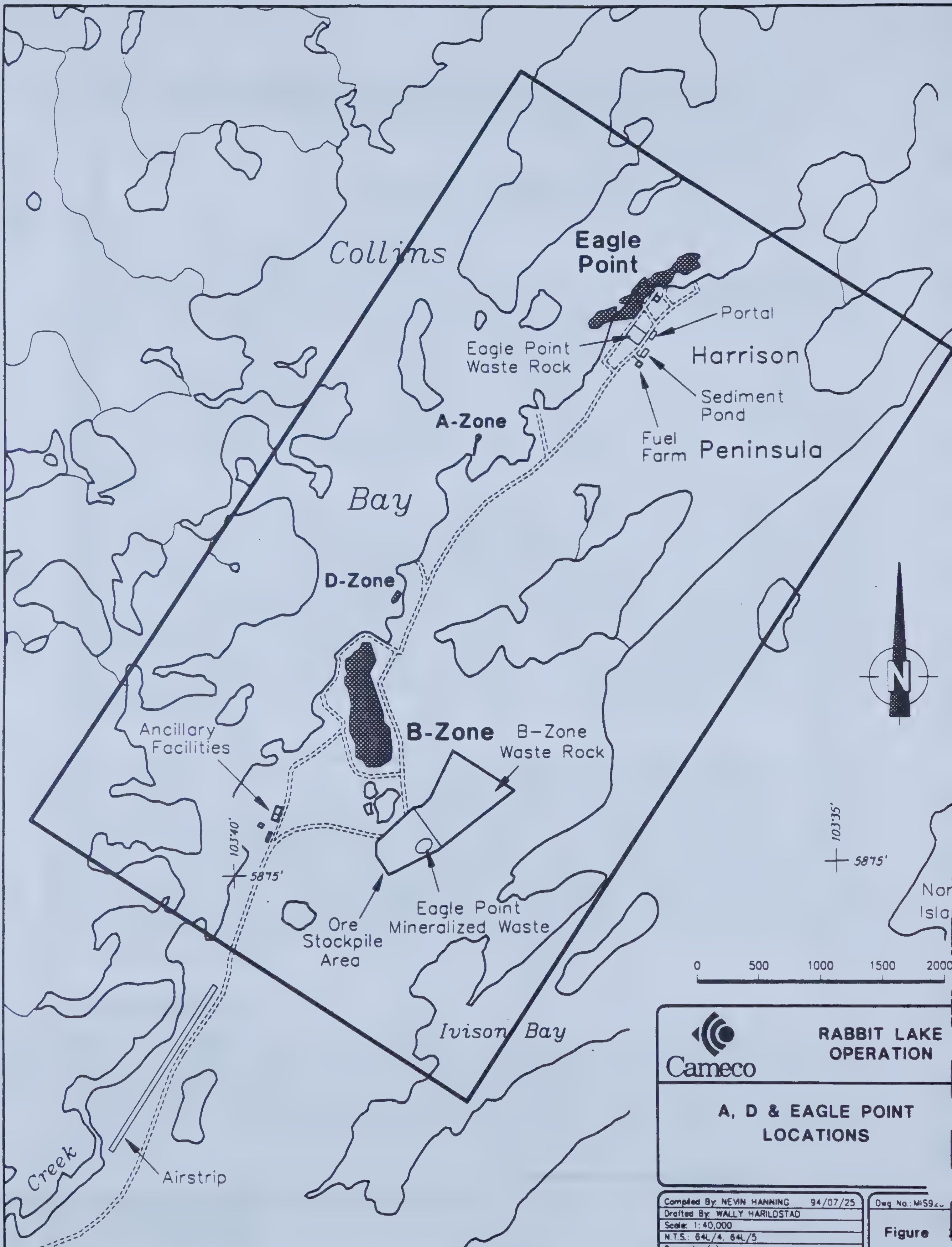
RABBIT LAKE OPERATION

LOCATION MAP

Compiled By: 93/12/20
Drafted By: WALLY HARILDSTAD
Scale: 1: 3,200,000
N.T.S.:
Disposition(s):

Dwg No. MIS91023

Figure 1


Collins
Bay
Eagle Point
Portal
Eagle Point Waste Rock
Harrison
Sediment Pond
Fuel Farm
Peninsula
A-Zone
D-Zone
B-Zone
B-Zone Waste Rock
Ancillary Facilities
103°40'
58°15'
103°35'
58°15'
Ore Stockpile Area
Eagle Point Mineralized Waste
Ivison Bay
Creek
Airstrip
N
0
500
1000
1500
2000
Cameco

RABBIT LAKE OPERATION

A, D & EAGLE POINT LOCATIONS

Compiled By: NEVIN HANNING 94/07/25
Drafted By: WALLY HARILDSTAD
Scale: 1:40,000
N.T.S.: 64L/4, 64L/5
Disposition(s):

Dwg No.: MIS9

Figure

situated between the former (and much larger) B-zone ore deposit and the currently mined Eagle Point deposit. All of these deposits are situated along the north-west shore of Harrison Peninsula, which defines Collins Bay of Wollaston Lake. The original Rabbit Lake deposit was situated some 10-13 km south of these Harrison Peninsula deposits. The original Rabbit Lake deposit was a land-locked open-pit mine which now serves as the tailings management facility for the Rabbit Lake Operation.

The Harrison Peninsula ore deposit mining methods are defined by the depth of the deposit and proximity to Collins Bay. The B-zone deposit straddled the Bay's shoreline and was mined by altering the shoreline with a steel-cell dyke followed by open-pit excavation. The D-zone deposit, immediately north of the B-zone, extends 90 m offshore, under water depths which range up to 8 m. The A-zone deposit, located 4 km north of B-zone, is situated some 200 m offshore, completely submerged under Collins Bay in water depths that range up to 14 m. The currently mined Eagle Point deposit is located 4.8 km north of B-zone. It straddles the shoreline, but because of the depth of the ore, is being mined by underground methods.

Both the A- and D-zone deposits will be mined in a fashion similar to that used for B-zone, namely shoreline alteration with steel-cell dykes followed by open-pit excavation. The similarity to B-zone is not just in the mining method. From an environmental perspective, the nickel and arsenic contents of the A-, D-, and B-zone deposits make them different from the essentially nickel- and arsenic-free Eagle Point and Rabbit Lake deposits.

Both A-zone and D-zone deposits are characterized by uranium mineralization in clay-altered lenses hosted in sandstone formations. The sandstone is underlain and bordered by basement gneisses and paragneisses rock and covered by overburden sandy tills. Concerns with variable nickel, arsenic, and sulphur contents in waste rock and tills surrounding the deposits, and the degree to which they are associated with uranium were the fundamental technical questions addressed in pre-development environmental planning. These factors, along with the inevitable comparison with current B-zone environmental performance largely shaped waste rock management and decommissioning plans.

Key comparative parameters between the three Harrison Peninsula open-pit developments are as follows:

Location	Ore Grade (% U_3O_8)	Ore Volume (m^3)	Waste Volume (m^3)	Impoundment Dimensions	
				Size (ha)	Water Volume * (10^6 m^3)
B-Zone	0.7%	1,000,000	5,600,000	28	5.2
A-Zone	5.7%	54,000	340,000	10.5	0.8
D-Zone	2.2%	46,000	500,000	6.5	0.6

* Based on proposed decommissioning plan.

At B-zone, the open pit was flooded shortly after completion of an eight year (1984-1991) mining phase. Prior to flooding, approximately 430,000 m^3 of waste rock and 100,000 m^3 of special waste were placed in the bottom of the pit. The special waste (sub-economic uranium mineralization) was covered with 2 m of till prior to flooding. Mineralized zones on the pit walls were left exposed and the dyke was left intact. Within the flooded pit, arsenic and nickel concentrations are the only two parameters which are currently above Saskatchewan Surface Water Quality Objectives (SSWQO) for protection of the quality of aquatic habitat. The arsenic and nickel are primarily soluble. Radionuclide and total suspended solids concentrations are very low. The flooded pit has no measurable impact on Collins Bay, by virtue of the dyke and relatively low contaminant concentrations. Current decommissioning issues associated with the former B-zone development can be summarized as follows:

- Current model predictions indicate that, if the pit is left as is, arsenic and nickel could take up to 200 years to reach SSWQO from their current levels (both at about 0.3 mg/L). Recovery rate is primarily governed by contaminant leaching from oxidized pit wall mineralization and contaminant removal by phytoplankton. Methods to accelerate or augment the natural recovery process are under active investigation.

- The long-term stability of water levels within the flooded pit is currently an open question. If water levels continue to rise, water handling procedures may become a primary "driver" in the decommissioning plan.

- The relatively large waste rock pile generated from the mine development is about 50% overburden and 50% waste rock. Although this pile can generally be characterized as a non-mineralized, non-acid generating source, localized seeps from the toe of the pile exhibit low pH and arsenic/nickel concentrations well above applicable SSWQO. Mechanisms which generate these seeps include localized pockets of acid-generating basement rock, impact of first-flush oxidized residual mineralization and thawing of initially trapped pore water. In the post-operational decommissioning phase, water collection and treatment facilities will no longer be available. The assimilative capacity of surrounding wetlands and effectiveness of till covers are being investigated.

Decommissioning Plan Development Work

Against the backdrop described above, it was decided to drill both A- and D-zone deposits a second time. During the winter of 1993/94, 57 holes were drilled. Locations were chosen to minimize entry into the ore body and maximize entry into the mineralized halo and waste rock surrounding the ore bodies. Samples were categorized as overburden, sandstone and basement rock. In total, the following analyses were done:

Test	Number
• Comprehensive Solids Analysis	521
• Acid-Base Accounting	39
• Short-Term Static Leach Extractions (Shake-flask tests)	26
• 20-Week Kinetic Leach Extractions (Column Tests)	
- Unsaturated	12
- Flooded	6

Drill hole log data and chemical analysis data were coupled with data from the original exploration phase definition drilling conducted prior to 1985. Assays from exploratory drilling had predictably focused on uranium and nickel analysis, with very little information available for arsenic and no data available on total sulphur. All available data were fed into a finite-element geological and statistical program (SERMINE, developed by Cogema). The model calculated average metal content for 7.5 m × 7.5 m × 3 m blocks by kriging drill hole analytical results (interpolation technique). Based on past experience, care was taken to exclude the ore body when calculating metal grades in the waste rock halo. Results were compared with the following waste classification criteria:

Parameter	Clean Waste Rock (%)	Environmental Special Waste (ESW) (%)
Arsenic	≤0.02	>0.02
Nickel	≤0.02	>0.02
Sulphur	≤0.20	>0.20
Uranium Oxide	<0.03	≥0.03 to ≤0.14

From this modelling, it was determined that in both A-zone and D-zone pits, the majority of the material to be removed is overburden, with basement rock removed in the easterly (shore) side of the pit and sandstone on the westerly side, in conformance with the general behaviour of the Collins Bay fault which runs through these deposits.

In summary, the following estimates were made from block modelling, assuming an ability to correctly classify each block:

Waste Rock Type	A-Zone (% of total mass)	D-Zone (% of total mass)
Overburden		
Clean	64.3	87.3
ESW	4.1	1.4
Sandstone		
Clean	8.3	4.6
ESW	5.2	2.1
Basement Rock		
Clean	-	3.9
ESW	18.1	0.7
Overall Totals		
Total Clean	72.6	95.8
Total ESW	27.4	4.2
Total (excluding ore)	100%	100%

When coupled with results from leach extraction tests, the following overall conclusions were derived:

For overburden: Metal concentrations are low, and the material is not acid generating. Use of a conventional radiometric scanner to segregate on uranium content will effectively control arsenic and nickel contents as they are closely correlated. The material is suitable for either subaerial or subaqueous management.

For sandstone: Segregation on uranium content will effectively control arsenic, nickel, and sulphur contents, but not completely. Without chemical assay, pockets of contaminated waste rock are possible, particularly at lower elevations. Leachate quality is improved under subaqueous conditions relative to subaerial conditions.

For basement rock: Metal concentrations are generally higher than in sandstone. Segregation solely on uranium content will not control nickel content sufficiently well and the rock is potentially acid generating. All basement rock should be considered Environmental Special Waste and would behave better if disposed of under water. Metal grades in D-zone basement rock are generally lower than in A-zone basement rock, although kinetic tests still generate elevated leachate nickel levels.

The most important conclusion from this work is that while some overburden from both A-zone and D-zone contains over 0.03% U_3O_8, which can be segregated by radiometric scanning, overburden with less than 0.03% U_3O_8 contains low-metal values, is non-acid generating and could be used for cover material.

The ratio of pit volume to water volume, and the minimal bulking factor associated with overburden tills have a major impact on what is and what is not practical, in terms of pit decommissioning. It is clearly not feasible to fill both open pits to the height of the dyke walls without importation of large volumes of clean material.

The level of correlation between arsenic, nickel, sulphur and uranium levels in the majority of the waste make the proposed waste rock classification criteria workable without resorting to detailed chemical assay to provide the necessary controls on waste rock segregation. Use of conventional mining radiometric scanners and horizon elevation control can provide the necessary segregation.

Developed Reclamation and Decommissioning Plan

As might be expected, there is a wide variety of decommissioning alternatives available for the A-zone and D-zone developments. There is also the option of integration with B-zone plans.

In all, nine scenarios were considered. A version of the Uranium Tailings Assessment Program (UTAP) was used to evaluate all scenarios. This model includes both source term estimation and environmental transport models, structured to predict impact on defined receptor groups. Non-radiological parameters can be evaluated by concentration or receptor uptake. Radiological parameters can be evaluated by receptor committed dose. A number of variables (such as initial contaminant concentrations and maximum source term leachate mass estimates) are input as probability distributions in order to predict impact range at any given time and place.

Various assumptions regarding the effectiveness of waste rock/environmental special waste (ESW) segregation were made in this modelling, ranging from chemical assay of each mined block to a combination of radiometric scanning and horizon elevation control to achieve compliance with the proposed waste rock classification criteria. Modelled scenarios also considered a variety of disposal options for clean waste rock and ESW, with clean overburden materials disposed of beside completed pits, moved back into the completed pits, or moved to the B-zone waste rock pile to help improve precipitation seepage control. In all scenarios, ESW materials were relocated back into their original pit, or consolidated into the D-zone pit. The D-zone pit, although larger than the A-zone pit, would require less fill if one wished to avoid ponded water behind a dyke, given the smaller size of the overall impoundment. Even in this consolidation scenario, ponded water cannot be avoided unless one uses the bulk of mined clean overburden as pit fill. One model run considered the long-term impact of breaching all three dykes.

Overall conclusions were as follows:

- Permeability control on the B-zone waste rock pile has little effect on the water quality in the B-zone pit. This is because peak concentrations in the pit are related to initial flooding/solubilization of oxidized wall rock and not the result of loadings from the contaminant front slowly migrating from the waste rock pile much further in the future.

- Within the flooded A-zone pit, peak concentrations for all modelled parameters are expected to remain below SSWQO except for nickel. Without intervention, it would take about 10-20 years to reach SSWQO in a closed A-zone pit. Peak concentrations for all parameters occur immediately after flooding.

- Within the flooded D-zone pit, which generally has greater water cover and reduced ESW quantities compared to A-zone, peak concentrations for all modelled parameters are expected to remain below SSWQO.

- The relatively elevated metal concentrations seen in the B-zone pit are not expected to be repeated in either the A-zone or D-zone flooded pits due to the mining methods used. While the B-zone pit walls were exposed to oxidizing conditions for almost eight years, the A-zone and D-zone pits will be mined during one winter each.

- As expected, dyke breaching significantly shortens the time necessary to meet SSWQO within the former impoundments. With limited breaching and minimal efforts to promote water exchange with Collins Bay, times to meet SSWQO are generally in the range of one half of those predicted for a closed pit.

- Regardless of the decommissioning scenario chosen, there will be a non-measurable effect on water quality in Collins Bay or Wollaston Lake.

- Receptor dose assessment shows that total dose attributable to A-zone, B-zone and D-zone decommissioning is a very small fraction of natural background radiation.

In selecting decommissioning options for the two new open-pit developments, Cameco took a conservative approach on clean vs. contaminated waste segregation. In both cases, elevations have been established above which there is reasonable confidence that grade control and conventional radiometric scanning will generate a clean overburden till pile. This clean material will be stockpiled beside the open pit, to temporarily serve as a pad for the material below the cut-off elevation. All material below the cut-off elevation will be classified as ESW and will be relocated back into the pit and covered with clean till prior to mine flooding. The volume of expected clean material included as ESW by simple grade control does not justify the cost to segregate it out by chemical analysis:

Category	A-Zone	D-Zone
Estimated Actual ESW Volume Below Cut-Off Elevation	102,000 m^3	23,000 m^3
Estimated Clean Waste Volume Below Cut-Off Elevation	92,000 m^3	57,000 m^3
Total Waste to be Relocated to Pit	194,000 m^3	80,000 m^3
Additional Till Cap Volume Placed Prior to Flooding	102,000 m^3	55,000 m^3
Till Material Retained For Other Reclamation Purposes	45,000 m^3	368,000 m^3

Prior to flooding, upper benches of the pit at the water surface contact point will be sloped and rip-rapped with clean waste rock to prevent shoreline erosion and associated TSS loadings to the water column. When water quality has reached levels acceptable to the regulatory agencies, Cameco will seek approvals to breach the dyke at the abutments to allow free exchange of surface waters. Accelerated mining over winter months should minimize contamination of the clean till used to temporarily store the ESW beside the pit.

Since all A-zone and D-zone sandstone and basement rock is being treated as ESW, the need for field verification is reduced to testing the clean overburden till piles. Daily and weekly composite samples will be taken to verify performance against the criteria. If failure is indicated, the material will be treated as ESW. In practical terms, this means either immediate removal of the ESW overburden material if the problem is extensive, future segregation when the till pile is relocated for other purposes, or consideration of a low permeability engineered cover in the unlikely event that the till pile is left in place.

Development of these two ore bodies also involves compensation for the loss of fish habitat resulting from the construction of the two impoundment dykes. Following a thorough fish spawning and habitat investigation of Collins Bay in 1994, Habitat Compensation Agreements were reached with Provincial and Federal regulatory agencies. The two agreements call for construction of 5,500 m^2 of lake whitefish spawning shoals and 10,250 m^2 of shallower marsh habitat.

Current Project Status

The regulatory approval process leading up to production mining has been arduous when one considers that the first regulatory submission which included A- and D-zone developments was filed in May, 1986. Final production approval was issued by the Atomic Energy Control Board (AECB) on September 21, 1995 and by Saskatchewan Environment and Resource Management (SERM) on September 25, 1995. At D-zone, overburden stripping is under way, in anticipation of production mining over the 1995/96 winter. This will be followed by waste backfilling in the spring of 1996 and reflooding in the summer of 1996. At A-zone, construction work has commenced on the dyke structure. Mining is scheduled for the winter of 1996/97, following a time line similar to D-zone development. SERM has approved the proposed decommissioning plan summarized in this paper. AECB on the other hand, has requested some additional modelling work prior to endorsement of the plan. At a minimum, the work completed to date has demonstrated that waste rock and decommissioning issues can be mitigated.

Reclamation and Decommissioning Issues

In developing the reclamation and decommissioning plan for A- and D-zone developments, we have attempted to develop a plan which addresses the environmental "drivers" which define the performance of the former, and much larger, B-zone development. Segregation of waste rock to clean and potentially problematic categories provides more decommissioning alternatives. Minimizing the time in which residual mineralization in pit walls is allowed to oxidize by using a compressed mining schedule centred around winter months to slow oxidation rates should reduce contaminant leaching into the flooded pit. Subaqueous disposal of problematic waste rock under a till cap should reduce leachate generation rates and problems with surface disposal of residual waste stockpiles. Preservation of clean stockpiles of overburden tills and lake bottom organics make economic and environmental sense. These stockpiles are a valuable commodity in other decommissioning work to be undertaken at the Rabbit Lake site. The selected waste segregation technique is compatible with a compressed mining schedule and represents a balance between segregation costs and efficiency.

The concept of creating an artificially impounded body of water with eventual hydraulic connection to Collins Bay produces mixed opinions amongst those who rule on decommissioning proposals for these open-pit mines. In our view, the issue reduces to the credibility of the modelling predictions. These predictions, based on current understandings of the mechanisms which govern the concentrations of nickel and arsenic in flooded pit water, forecast that the steps proposed should generate flooded pit water qualities which are about one order of magnitude better than those seen in the B-zone pit. If we were to completely backfill the A- and D-zone pits, we would obviously eliminate any possibility of short-term development of an isolated body of water which would be above SSWQO established for the protection of aquatic habitat. However, in terms of loading to the environment, this solution would produce limited, if any, benefit at a relatively high cost.

If the modelling predictions prove accurate, then the water quality in the flooded pits should lead to a straightforward approval process to breach the dykes and allow free exchange of surface waters, within a reasonable time frame. If the modelling predictions prove wrong, or if the approval process becomes untenable, then some form of contingency would need to be implemented. Four possible alternatives could be considered:

- Accelerate the natural recovery process as being investigated for the flooded B-zone pit,
- Implement some form of pump-and-treat system to accelerate recovery from the "first flush" mechanism,
- Undertake some interim controlled release phase prior to undertaking the work to remove all or part of the dyke, thereby demonstrating control of any environmental impact from the work, or
- Drain the flooded pits and fill them with clean waste material.

In any event, we believe that we have demonstrated that these two mine developments can proceed in an environmentally-responsible fashion.

ENVIRONMENTAL MANAGEMENT FOR MINING

Biopolishing Process for ^{226}Ra Removal

M. Kalin, M.P. Smith
Boojum Research Limited
468 Queen St. E., Box 19
Toronto, Ont. M5A 1T7

M. Wittrup
Cameco Corporation
2121-11th St. W.
Saskatoon, Sask. S7M 1J3

Biopolishing Process for ^{226}Ra Removal

M. Kalin, M.P. Smith, Boojum Research Limited
M. Wittrup, Cameco Corporation

ABSTRACT

^{226}Ra is weathered from waste rock and fluxing from sediments, which have been deposited downstream from the former Rabbit Lake ore deposit in the Link Lake drainage basin in northern Saskatchewan. Lower Link Lake, below the effluent discharge point is populated with *Nitella flexilis*, an algal species of the Characeae with a high affinity for ^{226}Ra. The use algae to contain ^{226}Ra within the drainage basin is evaluated, through the establishment of an algal population in Upper Link Lake. This lake is void of algae and located upstream from the effluent discharge point. As concentrations of ^{226}Ra in the algal biomass were determined as high as 60 Bq/g dry weight, it could be expected that a healthy algal population growing in this location would reduce ^{226}Ra load from the sediments of former Rabbit Lake to the water in Upper Link Lake.

In 1989, 12 tonnes (fresh weight) of *Nitella* were transplanted to Upper Link Lake. The development of the algal population was monitored over five growing seasons. After five years the algal biomass has increased 13 times since transplanting. The growth dynamics of the algal populations suggest, that during one growing season, due to continued growth and decay the population is replaced once. The standing biomass of *Nitella* contained a total of 1.0×10^8 Bq of ^{226}Ra. This is based on estimates of total biomass present in the lake and its concentrations. Load calculations indicate that the algal population retains about 3.9×10^8 Bq of ^{226}Ra in the biomass and in the sediment. This quantity represents about 65% of the annual loading arriving at the discharge point. The algal populations growing over the former Rabbit Lake sediments reduce the ^{226}Ra flux from this area into Upper Link Lake water. Monitoring data at the discharge point, show a reduction in the seasonal fluctuations of ^{226}Ra concentrations after 5 years of growth. These reductions are evidence of the effectiveness of the algae in retaining ^{226}Ra in the drainage basin.

INTRODUCTION

Contaminant removal using natural water-cleansing processes might represent an alternative to perpetual water treatment at the time of decommissioning a mining operation. Such contaminant removal is possible when specific ecosystem characteristics are created within the waste management area and if the contaminant to be removed is geochemically amenable to natural removal. If these two basic conditions are fulfilled, through ecological engineering measures, chemical water treatment requirements can be reduced or replaced.

The Rabbit Lake drainage basin was identified as an ecosystem, where within the waste management area, algal populations are present, which have the ability to remove ^{226}Ra from the water column. These algae grew in the lakes of the drainage basin, prior to commencement of the mining activities. During operation of the mine water quality monitoring data indicated that the concentration of ^{226}Ra decreases upon passage through a bog located between Upper and Lower Link Lake.

Nitella flexilis, a species of attached algae dominates submerged vegetation in this bog. High concentrations of ^{226}Ra in the algal biomass sampled from the bog, confirmed the algae reported affinity for this contaminant. These algae are known for their affinity for ^{226}Ra, as well as for other radionuclides (^{210}Pb, ^{90}Sr, ^{137}Cs, ^{106}Ru), alkaline earth elements and metals (Mudroch & Capobianco, 1978; Dusauskene & Polikarpov, 1978; Harding & Whitton, 1978).

It was proposed to utilize these algae to control contaminant release from Upper Link Lake to the lower parts of the drainage basin. As part of the restoration measures for the decommissioning of this drainage basin, the recolonisation of Upper Link Lake with these algae was evaluated along with a quantification of the capacity of contaminant retention and water cleansing capacity.

The distribution and growth of the algae

Between 1988 and 1989, the distribution and growth of the algae, *Chara vulgaris* and *Nitella flexilis*, both members of the Charophyte family, were studied in the Rabbit Lake drainage basin (Kalin and Smith 1988). Extensive populations of *Nitella* were growing in the bog and in Lower Link Lake, but the algae were entirely absent in Upper Link Lake. The discharge of the Rabbit Lake sediments to Upper Link Lake altered water depth and covered any vegetation with solids. Sediment cores collected during hydrological investigations of Upper Link Lake contained oospores of the algae, suggesting its presence prior to the onset of mining activities.

Growth of the algae was tested in experimental plots in Upper Link Lake through transplanting biomass from Lower Link Lake. Biomass production ranged between 20 g dry weight.m^{-2} to 560 g.m^{-2} per year. It was estimated, based on the concentrations of ^{226}Ra (^{10}Bq.g$^{-1)}$, that a 10 ha underwater algal meadow, with a biomass density of about 250 g *Nitella*.m^{-2} could potentially reduce the total annual ^{226}Ra load by 2.5 x 10^{8} Bq per year at the discharge point, referred to as Sedimentation Dam (station W15) at the outflow of Upper Link Lake.

With these contaminant retention estimates at hand, the utilisation of the algae as a natural cleansing process as part of the decommissioning plan was further pursued. In 1988, *Nitella* biomass was transplanted from lower Link Lake to Upper Link Lake. The algae grew very well and a larger scale transplant operation was initiated in 1989.

Prior to 1993, the amount of *Nitella* biomass outside the transplant zones was negligible. However, in 1993 it is estimated that in some transplant zones the amount of biomass is 7 times that transplanted in 1989. It required four growing seasons for the new transplanted *Nitella* population's total biomass to make large net gains compared to the initial biomass transplanted on the submerged parts of the former Rabbit Lake sediments and in other parts of Upper Link Lake.

During the 1989 - 1993 period, the *Nitella* weight gain was approximately 4 tonnes dry weight, or almost 8 times the original biomass transplanted.

During one year of growth it is estimated that 1 tonne of biomass is lost due to fragmentation/transport of parts of the algae or decay, leaving a biomass approximately 6 times that originally transplanted.

In 1994 it appears that the colonization phase (spread and infill) of the *Nitella* population development in two of the transplant zones is almost finished, given the near-complete coverage of the available surface area. Thus in five years extensive colonization had taken place in Upper Link Lake.

Chemical characteristics of the Rabbit Lake drainage basin

From an ecological point of view, the water characteristics of the drainage basin are essentially those of a healthy freshwater ecosystem. The pH of the water is neutral, ranging from pH 7 to 8. The sulphate concentrations, although they decrease in the outflow of Lower Link Lake (W25) from an average of around 50 $mg.L^{-1}$ (W5) to 20 $mg.L^{-1}$, are in the mid range for fresh water in Central Canada (not detectable to 77.3 $mg.L^{-1}$ based on 4696 samples; CCREM, 1987). Chloride concentrations are typical for fresh water, ranging throughout the drainage basin between 1 and 5 $mg.L^{-1}$. The concentration range for Central Canada for chloride is given as <0.1 to 450 $mg.L^{-1}$ (CCREM, 1987). Specific conductivities of 100 to 200 $\mu S.cm^{-1}$ are somewhat higher than in other northern lakes in the region (McArthur River area, 5 to 43 $\mu S.cm^{-1}$; Cigar Lake area, < 6 to 27 $\mu S.cm^{-1}$; M. Wittrup pers.com., 1994).

^{226}Ra with a mean annual average of about 0.3 $Bq.L^{-1}$ is elevated. These concentrations are above natural background concentrations, which are reported as < 0.005 $Bq.L^{-1}$ for Wollaston Lake, <0.005 to 0.06 $Bq.L^{-1}$ in the McArthur River area (M.Wittrup, pers. com., 1994), and to average across Canada from 0.008 $Bq.L^{-1}$ to 0.1 $Bq.L^{-1}$ (Buchnea & van der Vooren, 1985). Average uranium concentrations in the Link Lake drainage basin are elevated above the Link Lakes, with 3 to 4 $mg.L^{-1}$ and drop to a range of 0.2 to 0.4 mg.L^{-1} at Lower Link Lake outflow. Natural background ranges in the McArthur River area from < 0.05 to 2.3 μg.L^{-1} (M. Wittrup, pers. com. 1994) and, in non-mineralized areas across Canada, from 0.04 to 1.4 μg.L^{-1} (Buchnea and van der Vooren 1985). These elevated concentrations of both ^{226}Ra and U are targeted to be removed in Upper Link Lake utilizing algal removal.

Contaminant form and its distribution in the drainage basin

The form in which the contaminants are present in the water is relevant with respect to their removal. Suspended ^{226}Ra, quantified by the difference in concentrations of ^{226}Ra between whole samples and filtered (3 μm) samples, can be removed through sedimentation of the carrier particles. Carrier particles include unicellular algae and other organic debris which adhere to *Nitella* or other periphyton populations.

For ^{226}Ra the dissolved and suspended concentrations are plotted in Figures 1a for water entering Upper Link Lake (Station W5 , Airport Road) and for the water leaving Upper Link Lake (Station W15, Sedimentation Dam) in Figure 1b. Generally, most ^{226}Ra is present in the dissolved form. On the average, the ratio of dissolved to total ^{226}Ra throughout the drainage basin does not change markedly.

It can be noted, that particulary during spring run-off (Figure 1a and 1b) the ^{226}Ra concentrations increase between W5 and W15. The annual averages are 0.14 to 0.36 Bq.L^{-1} compared to 0.28 -0.5 Bq.L^{-1}. Within Upper Link Lake above the Narrows a further distinction can be made, with respect to the source of ^{226} Ra the annual average concentrations range at the Narrows between 0.29 to 0.57 Bq.L^{-1}. This increase in concentration is due to a ^{226}Ra flux from the sediments of the former Rabbit Lake, located above the Narrows monitoring station in Upper Link Lake.

Fig.1a: W5, Airport Road
[Ra226], 1987 -1994

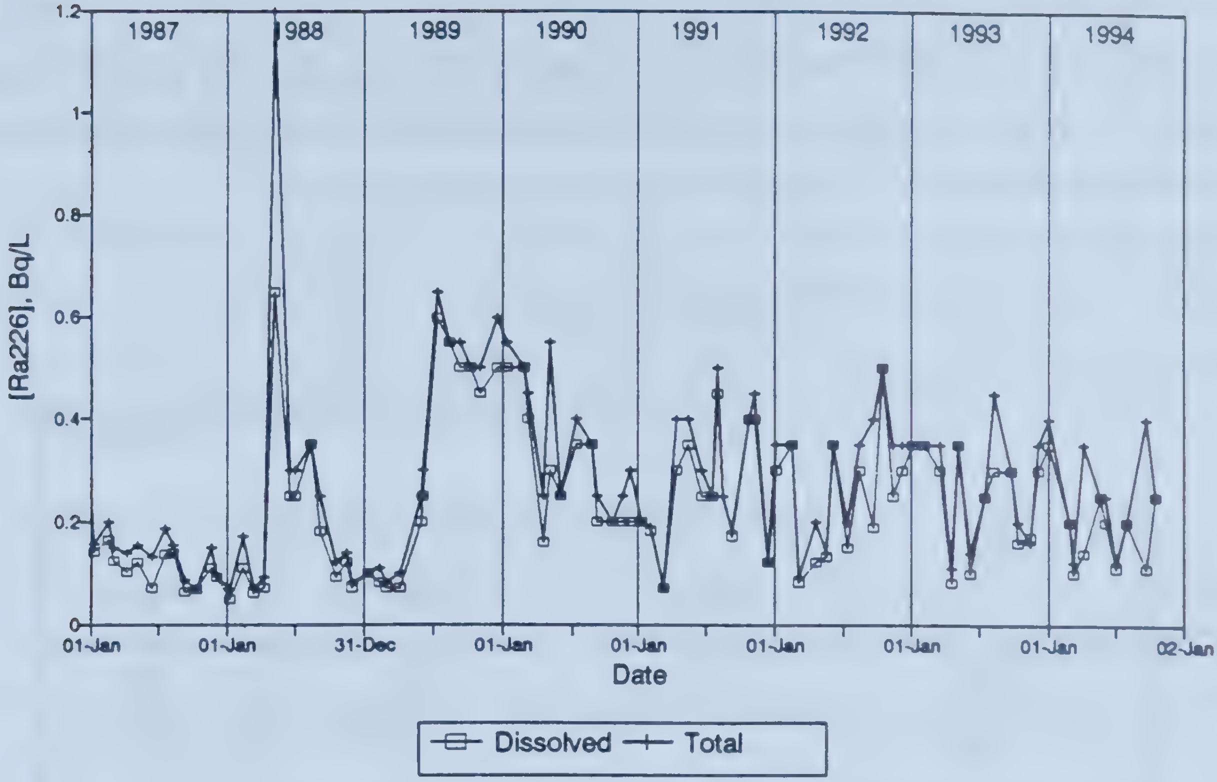
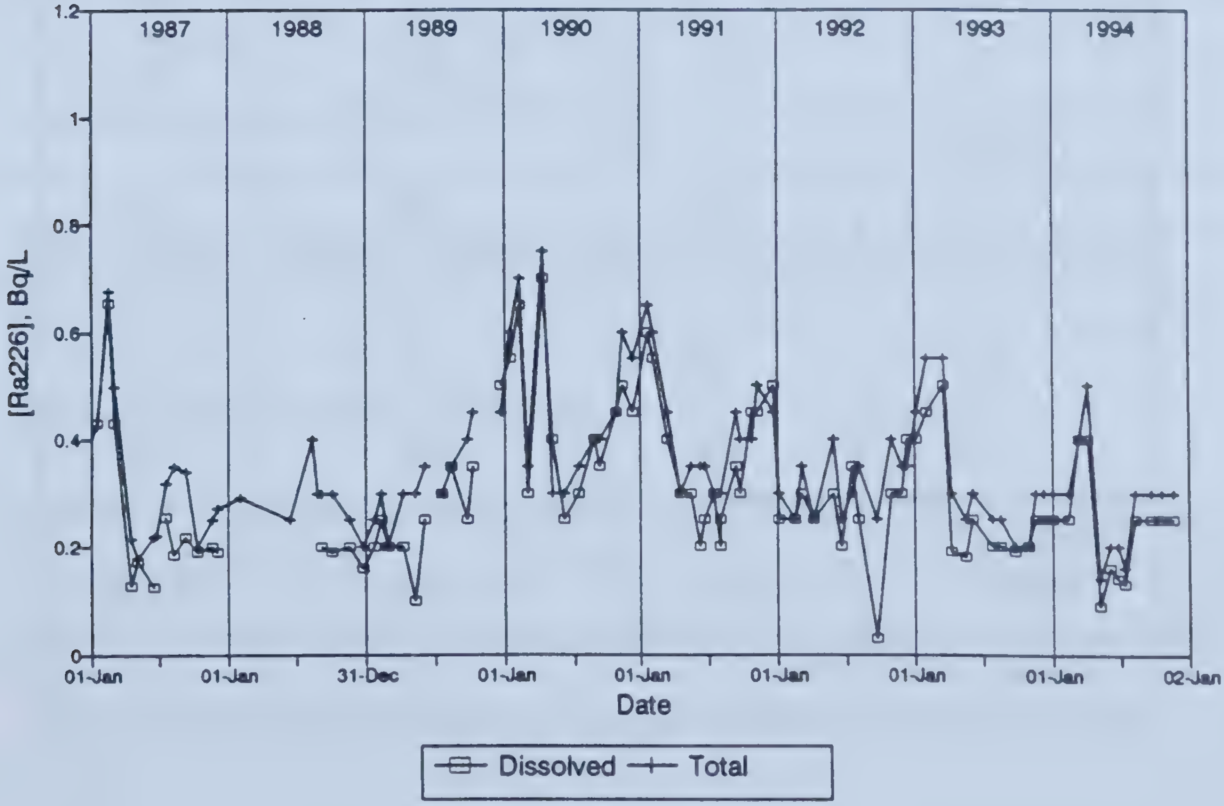


Fig.1b: W15, Sedimentation Dam
[Ra226], 1987-1994



At the outflow of Lower Link Lake a reduction is evident with annual average concentrations ranging from 0.04 to 0.1 Bq.L^{-1}.

In Table 1 the annual ^{226}Ra loads are presented for the upper part of the drainage basin. The load is calculated using actual and estimated flows for these stations and the concentrations of ^{226}Ra from the monthly water quality data.

Table 1: Annual ^{226}Ra Load at W5 and W15

Year	W5 Airport Road (MBq)	W15 Sedimentation Dam (MBq)	Difference W15 - W5 (MBq)
1987	129	478	349
1988	492	675	183
1989	272	634	362
1990	179	581	402
1991	236	633	397
Average 1987-91	261	600	339
1992	257	578	321
1993	198	346	148
1994	170	258	88
Average 1992-94	208	394	186
Average, 1987 - 1994			281

The annual loads of ^{226}Ra are summarized for several years for different two locations, water entering Upper Link Lake (W5) and leaving Upper Link Lake at Sedimentation dam. The annual ^{226}Ra loading at W5 between 1987 and 1991 ranged from 129 and 492 MBq of ^{226}Ra, averaging 261 MBq.year^{-1} (Table 1). In the same years 478 and 674 MBq ^{226}Ra arrived at W15 averaging 600 MBq.year^{-1}.

The differences in annual load between the stations is calculated by subtracting the annual load at one station from the annual load at another station. These differences indicate whether the load increased from one station to the next (positive difference) or decreased (negative difference).

The average annual ^{226}Ra load increase between W5 and W15 is 339 MBq.year^{-1}. This value represents the average annual contribution by the sediments and the drainage basin of the entire Upper Link Lake area. For the period 1992 to 1995, starting 3 years after transplanting of the algae into Upper Link Lake, average annual loads are given in Table 1.

Since that time, the *Nitella* population was starting to grow in such quantities, that its effect on the loading could possibly be evident. Given the three years (1992-1994) average load at Airport Road (W5) with 208 MBq and at Sedimentation Dam (W15) of 394 MBq, a lower load of 394 MBq in these three years compared to the earlier period (1987-1991) of 600 MBq is evident. The differences in load between the two stations over this period is decreasing from year to year, suggesting further that as the algal population increases the flux from the sediments is retained by the algae.

Biological Polishing of Upper Link Lake

The ratio of dissolved and suspended fractions of ^{226}Ra (Figure 1a and 1b) indicate, that essentially removal has to take place of the dissolved fraction of ^{226}Ra. Thus biogeochemical processes including precipitation, coprecipitation or adsorption onto cell walls of zooplankton, phytoplankton, periphyton, and benthic species such as *Nitella* are the likely route of removal for this radionuclide, which is present in trace concentration.

If we assume that the biological material is facilitating these processes take place, it can be expected that the removal for ^{226}Ra displays a seasonal behaviour. Some seasonality is evident in the monitoring data (Fig 1a and Fig 1b). As the biological activity also affects the pH, and pH in turn affects surface adsorption and precipitation processes biological productivity and growth activity in the drainage basin have to be quantified.

Surveys of the drainage basin indicated in 1988 no *Nitella or* any other vascular macrophyte populations were present in Upper Link Lake in contrast to Lower Link Lake. Instead, Upper Link Lake was populated by blue-green (Cyanobacteria) phytoplankton populations in the lake at large, filamentous green (Chlorophyta) algal were growing in the upper part of the drainage basin and in the vegetated parts of the sediment delta. Periodic blooms of algae occurred in Upper Link Lake.

Five major ecological groups of algae populate the Rabbit Lake drainage basin (Table 2). Two types of Cyanobacteria (blue-green algae) cover the sediments (mat like and filamentous forms) in the drainage basin, dominating to different degrees in different sections of the basin. The filamentous forms prevail in ditches and in fast flowing water. Mats cover edges and slower moving portions of ponds and pools. The ^{226}Ra concentrations have been determined for these different groups and are given in Table 2. *Nitella flexilis* contains the highest concentrations followed by the filamentous green and blue green algae.

Table 2: [Ra^{226}] in Algal Biomass in the Rabbit Lake Drainage Basin

Algal Group	Ra^{226}, Bq/g dry weight		
	Range	Avg	n
Filamentous Cyanobacteria	9 - 21	14.0	6
Mat Cyanobacteria	5.5 - 10	8.5	6
Filamentous Chlorophyta	1.4 - 42	14.2	8
Nitella flexilis (determined between 1988-1992)	5 - 50	20.9	22
	13 - 43	24.2	10
	1 - 60	13.6	19
	0.6 - 9.5	2.6	16
Cyanobacteria Phytoplankton	0.25 - 0.8	0.5	2

These filamentous and mat species of blue-green algae contain, on average, significant concentrations of ^{226}Ra (14 and 8.5 Bq ^{226}Ra.g dry weight^{-1}, respectively)
The filamentous Chlorophyta (green algae), commonly found during the growing season in the streams passing through the vegetated Delta, on sediments and any available surfaces in Upper Link Lake and Lower Link Lake contain, on average, 14.2 Bq ^{226}Ra.gdw^{-1} .

Nitella biomass transplanted and grown in Upper Link Lake above and below the Narrows contains, on average, relatively high concentrations of ^{226}Ra (20.9 and 24.2 Bq.gdw^{-1}, respectively). Below the Sedimentation dam, in the bog where the ^{226}Ra reductions were originally noted in the monitoring data, *Nitella* biomass typically contains less ^{226}Ra (13.6 Bq.gdw^{-1}), while in Lower Link Lake, biomass contains only 2.6 Bq.gdw^{-1} on average. These concentrations in the biomass suggest, that the sediment / water concentrations of ^{226}Ra are related to those in the biomass.

The final algal group is phytoplankton which, in Upper Link Lake, are dominated by the Cyanobacteria. Species of this group are responsible for the periodic algal blooms observed in Upper Link Lake during the growing season. Algal biomass collected during blooms in Upper Link Lake contained, on average, relatively low concentrations of ^{226}Ra (0.5 Bq.gdw^{-1}).

Biological polishing capacity of a contaminant is not only dependant on the total concentration in the biomass, but also on the quantity of biomass produced with in the drainage basin. In biological terms this is referred to as productivity. In Table 3 the growth dynamics of the algal groups, relevant to ^{226}Ra removal are given.

Table 3: Growth Dynamics determined for the Rabbit Lake Drainage Basin

Standing Biomass, g dry weight/m^2	Range
Filamentous Cyanobacteria	379 - 895
Mat Cyanobacteria	95-110
Filamentous Chlorophyta	17 - 68
Nitella flexilis	1 - 1000
Cyanobacteria Phytoplankton	1 - 10 (2)
Primary Productivity, g dry weight/m^2 /year (1)	Range
Filamentous Cyanobacteria	4 - 69
Mat Cyanobacteria	4 - 69
Filamentous Chlorophyta	4 - 69
Nitella flexilis	1.5 - 5
Cyanobacteria Phytoplankton	113

(1) Source: Wetzel, 1983

(2) Estimated; average 2.6 mg dw/L

Depending on growth habit, the specific nutrient availability and growing conditions, each algal group will maintain specific standing biomass densities and growth rates. For instance, depending on the location in the Rabbit Lake drainage basin, *Nitella* standing biomass values can range from 1 to 1000 gdw.m^{-2} (including ash; Table 3).

Typically, higher standing biomass values have been determined in populations in areas of flowing water such the bog and the channel draining Lower Link Lake (up to 1000 gdw.m^{-2}), compared to open lake populations in Lower Link Lake (250 gdw.m^{-2} on average). Since Upper Link Lake is the focus of biological removal of ^{226}Ra, the value, 250 gdw.m^{-2} will be normally employed during projections of standing biomass for mature *Nitella* populations in Upper Link Lake.

The rate of apical growth and basal decay of *Nitella* indicated the productivity of the algae is such that new biomass each year equivalent to the standing biomass at any time. In other words, the *Nitella* biomass growth (productivity) replaced the standing biomass at least once each year. Wetzel (1983) describes this relationship as the Productivity and maximum standing biomass ratio. From his studies of Characean population dynamics, he estimates a higher ratio 3.3 suggesting that the biomass turns over 3.3 times per year, higher then in studies by Kalin et al. 1988.

The standing biomass of populations of filamentous and mat Cyanobacteria and filamentous Chlorophyta was determined for the drainage basin to average for filamentous Cyanobacteria was 250 gdw.m^{-2}, while for the mat populations 100 gdw.m^{-2}, and for the filamentous Chlorophyta, 40 gdw.m^{-2}. Growth rates for these populations can be reliably derived from the literature, as they are not very site specific, and Wetzel's ratio of productivity and maximum standing biomass will be used (Wetzel, 1983) in estimating polishing capacity.

Characteristic to Upper Link Lake is the periodically dense phytoplankton population during the growing season, dominated by Cyanobacteria. Total suspended solids concentrations range from 1 to 10 mg.L^{-1} (1987-1992), of which a large fraction is likely phytoplankton. Assuming an average depth of 1.4 m for Upper Link Lake, then the standing biomass of phytoplankton population averaged 3.6 gdw.m^{-2} (average TSS= 2.56 mg.L^{-1}, 1987 to 1992 Cameco monitoring data). From a summary of Productivity: Maximum Biomass ratios by Wetzel (1983), the ratio for phytoplankton averages 113 g/dry weight/m2/year (Table 3).

Overall, these estimates indicate that while *Nitella* populations can maintain relatively high perennial standing biomass, their productivity is low compared to the other algal groups in the Rabbit Lake drainage basin.

The biological polishing capacity for ^{226}Ra

A primary objective of the application of Ecological Engineering in the Rabbit Lake drainage basin is to reduce the total ^{226}Ra load leaving Upper Link Lake. With the biological growth data at hand, it is now possible to derive estimates of the expected retention of ^{226}Ra in Upper Link Lake.

The results of early studies of ^{226}Ra concentrations in plant materials in 1988 indicated that *Nitella flexilis* biomass accumulated higher concentrations (up to 25 Bq.gdw^{-1}) than any other aquatic plant population and that *Nitella* populations maintain a dense perennial standing biomass (250 gdw.m^{2}) covering the sediment, with the biomass renewing itself at least once per year (Kalin et al., 1988).

Further sampling and analyses of *Nitella* biomass between 1989 and 1992 indicated that even higher ^{226}Ra concentrations than originally determined are present in *Nitella* biomass. Up to 60 Bq.gdw^{-1} was determined in unwashed *Nitella* biomass, analyzed with particulates still trapped in the biomass (bog sampled in April 1990). Meanwhile, concentrations of ^{226}Ra in washed *Nitella* in samples from Upper Link Lake average 21 Bq.gdw^{-1} (above Narrows) and 24 Bq.gdw^{-1} (below Narrows).

Using the August 1993 total standing biomass estimates for *Nitella* in Upper Link Lake (Transplant Zones 1 and 2, 4.9 tonnes dry weight) and the above Narrows average ^{226}Ra content, this biomass currently contains a total of 1.02×10^{8} Bq of ^{226}Ra.

The *Nitella* population's total growth, or annual productivity, must exceed the maximum observed standing biomass to compensate for death and decay of older biomass. Wetzel (1983) suggests that the Total Productivity: Maximum Biomass ratio for Characean populations is approximately 3.3, or in other words, the *Nitella* population renews itself 3.3 times each year. If this value is used, a total of 3.9×10^8 Bq ^{226}Ra will be taken up by the *Nitella* population at its current size over the course of a year, a quantity of ^{226}Ra equivalent to the current annual contribution by the former Rabbit Lake sediments on the delta in Upper Link Lake.

Nitella is not the only algal population in Upper Link Lake; blue-green (Cyanobacteria) algal populations are usually dense and can form blooms during the growing season. If an average phytoplankton biomass of 3.6 $gdw.m^2$ is used, and contains, on average, 0.5 Bq $^{226}Ra.gdw^{-1}$, then the phytoplankton population harbours, on average, only 4.0 $x10^5$ Bq ^{226}Ra. However, according to Wetzel (1983), phytoplankton have, on average, a Productivity: Maximum Biomass ratio of 113, and over the course of a year, 4.5 $x10^7$ Bq of ^{226}Ra may be adsorbed onto phytoplankton cells. Most of this biomass will settle to the bottom and join the sediments of Upper Link Lake and the areas downstream.

Filamentous green (Chorophyta) algae have been observed to produce visible biomass during the growing season over the bottom of Upper Link Lake and attach to any available substrate. While the standing biomass of these filamentous green algae are minor, and may amount to only 1 $gdw.m^2$ during these periods, they contain 14 Bq $^{226}Ra.gdw^{-1}$. The total population could then harbour 3.1×10^6 Bq ^{226}Ra. Using a Productivity: Maximum Biomass ratio of 30, over the course of a year, 9.2×10^7 Bq ^{226}Ra may be adsorbed onto the filamentous green algal population.

CONCLUSION

The projection (Kalin et al. 1988) that the *Nitella* population will spread in Upper Link Lake to cover a total of 12 hectares (Kalin et al., 1988) still appears valid, given the growth and spreading pattern to date. If the approximately 9 ha of lake area with depths between 0.6 and 1.6 m support growth of 250 $gdw.m^{-2}$ *Nitella*, and the 3 ha of lake area with depths between 1.6 to 1.8 m support growth of 100 $g.m^{-2}$ *Nitella*, then the projected total *Nitella* biomass will be 25.5 t of *Nitella* dry weight. Using the average ^{226}Ra concentration in Upper Link Lake *Nitella* (22.6 $Bq.gdw^{-1}$), this *Nitella* population will harbour 5.8×10^8 Bq of ^{226}Ra, an amount nearly equivalent to the 1987-1992 average Upper Link Lake ^{226}Ra loading of 6×10^8 Bq of ^{226}Ra per year. This estimate may be somewhat conservative, as it does not account for possible reductions in net ^{226}Ra flux from Upper Link Lake sediments once the *Nitella* population covers the full 12 ha, and it assumes a *Nitella* biomass turnover of only once per year.

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1995 ENVIRONMENTAL MANAGEMENT FOR MINING CONFERENCE
CONFÉRENCE 1995 SUR LA GESTION DE L'ENVIRONNEMENT EN SECTEUR MINIER

THEME: "RECLAMATION AND DECOMMISSIONING"
THEME: "RÉHABILITATION ET MISE HORS DE SERVICE"

FALKLAND GYPSUM QUARRY, B.C., RECLAMATION PLAN
PLAN DE RÉHABILITATION, CARRIERE DE GYPSE, FALKLAND, C.B.

co-authors\coauteurs
MICHEL FONTAINE
CHRISTINE MADISON
Landscape architects\Architectes paysagistes

FONTAINE, BERNARD & ASSOCIÉS
1751, RUE RICHARDSON, SUITE 8100
MONTREAL, QUEBEC H3K 1G6
TEL:(514) 846-2171
FAX:(514) 846-2172

FALKLAND GYPSUM QUARRY, B.C., RECLAMATION PLAN
PLAN DE RÉHABILITATION, CARRIERE DE GYPSE, FALKLAND, C.B.

Michel Fontaine
Christine Madison

ABSTRACT:

In 1993 our landscape architect firm planned the reclamation of former, actual and future mining sectors of the Falkland Gypsum Quarry. A global and progessive approach was selected to enable a better visual and functional cohesion throughout the mining site and its evolution. Given its location in the Rockies and its extreme topography, the material being extracted, the proximity of the town and the site's glaring visibility, the Falkland Quarry offered a unique reclamation challenge.

Biophysical, visual and human factors were studied along with the detailed mining schedules and operations. Reclamation strategies were to produce an efficient and environmentally sound mining site with regards to its sociological context. The two main foci of the project were to create a responsive reclamation plan for the proposed quarry and to be open to the site's genius.

RÉSUMÉ:

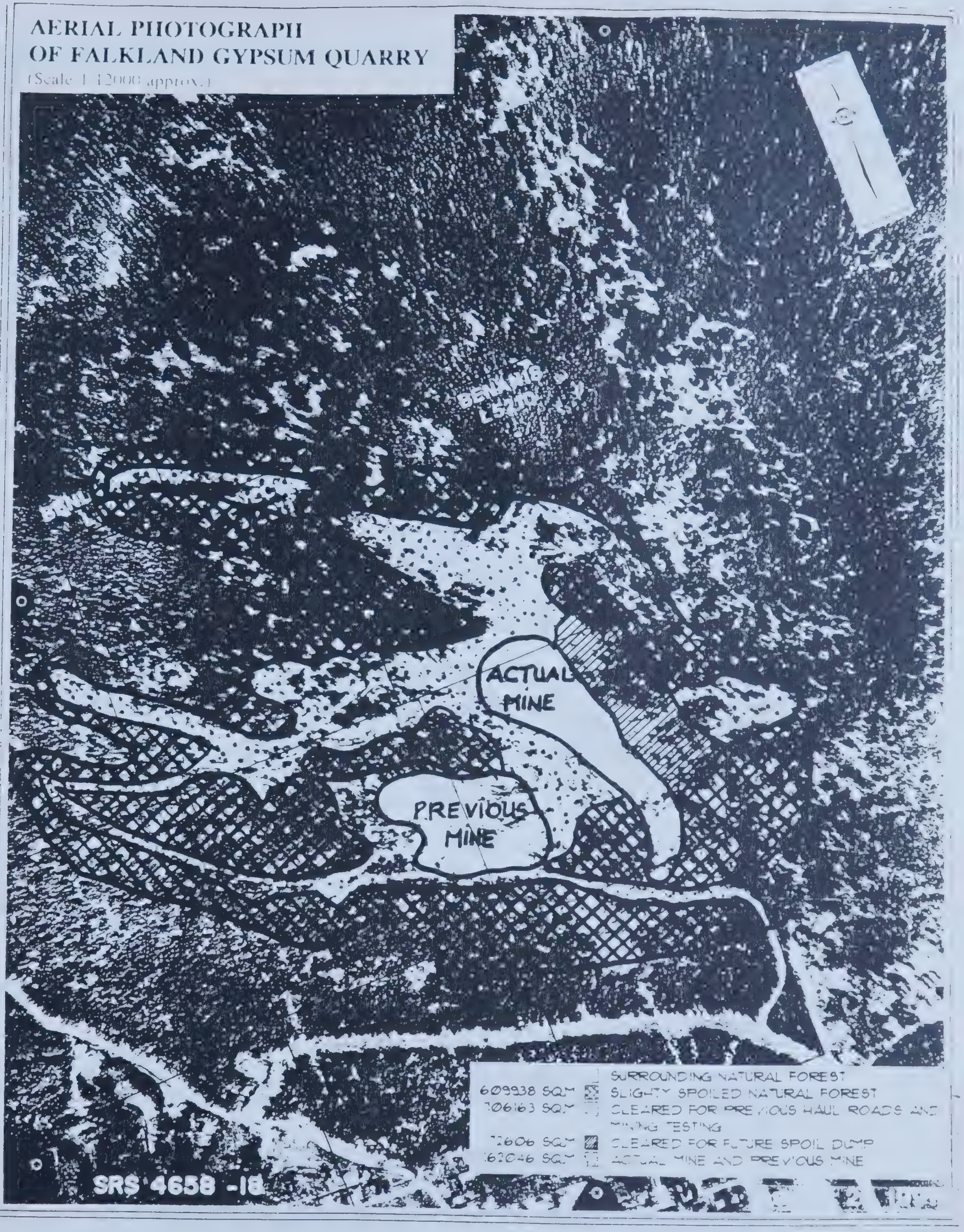
En tant qu'architectes paysagistes, nous avons élaboré un plan de réhabilitation progressif pour l'ensemble de la Carrière de Gypse de Falkland. Une approche globale de la problématique a permis de générer des stratégies d'aménagement offrant une bonne cohésion visuelle tout en assurant une logistique efficace entre les travaux de réhabilitation et le développement de l'exploitation minière. La topographie escarpée, la proximité de la ville et la grande visibilité du gypse, ont contribué à la complexité du projet. L'étude des composantes du site (biophysiques, visuelles, socio-économiques) et de la dynamique des plans miniers et leur développement pour les trente prochaines années ont permis de dégager les objectifs du projet:

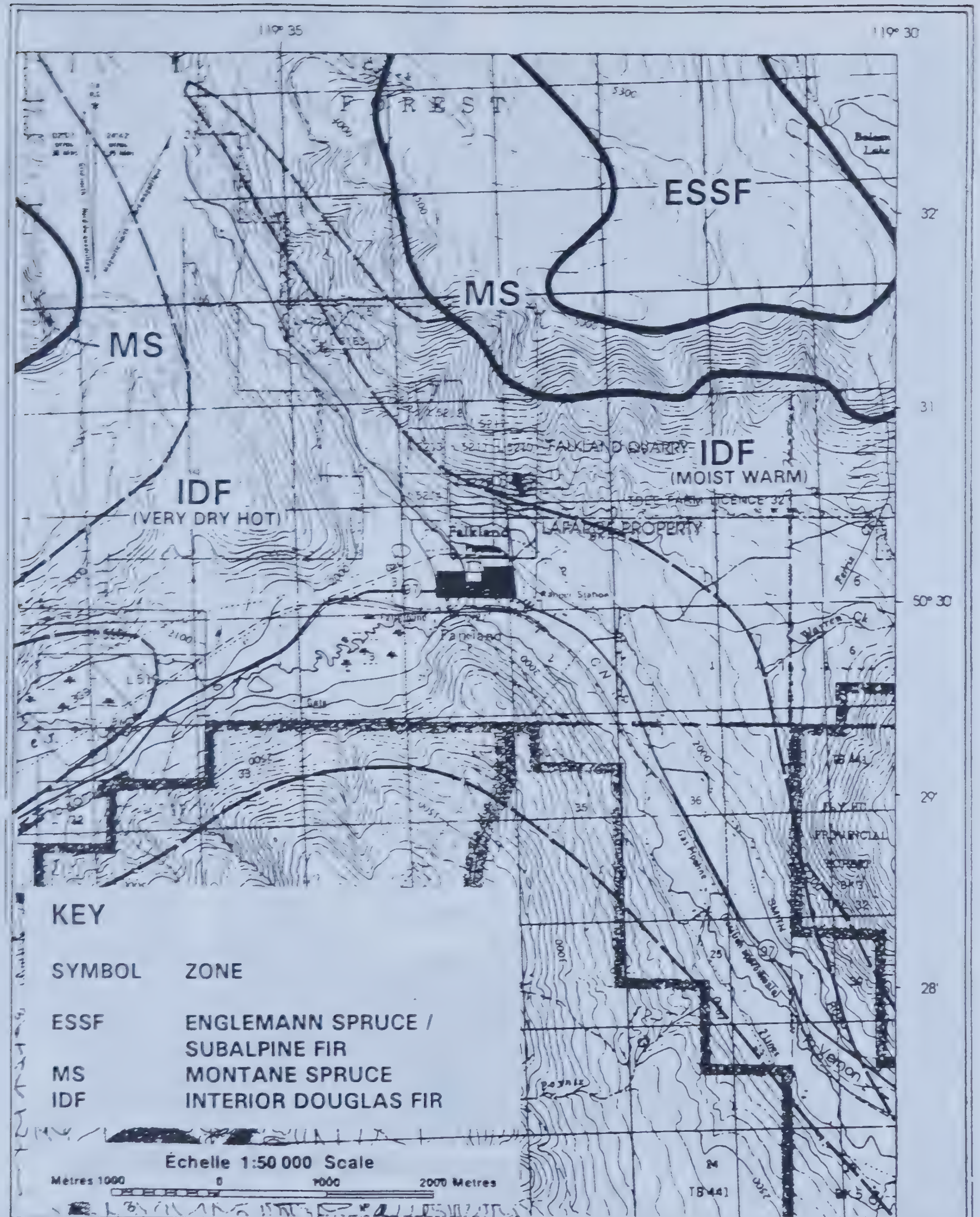
1. Etre conformes à la section 10 du Code des mines de la Colombie-Britannique;
2. Stabiliser et renaturaliser les espaces ouverts existants et les futures aires de dépôts;
3. Minimiser les impacts visuels des carrières présente et future ainsi que les impacts visuels des aires de dépôts de mort-terrain;
4. Renaturaliser la présente carrière et les routes de hâlage existantes;
5. Créer un aménagement paysager permettant, à certains endroits, le développement d'activités récréatives extensives.

Définies selon les phases de développement de la carrière et la gestion de mort-terrain, les stratégies de réhabilitation sont flexibles pour permettre une meilleure répartition annuelle des budgets de réhabilitation. Les plans produits illustrent les phases de la réhabilitation et les stratégies d'aménagement, en corrélation avec le plan minier. Présenté avec un accueil très favorable en 1993 à la Municipalité de Falkland, la réussite de ce projet repose sur sa sensibilité à l'environnement et son ouverture envers le génie du lieu.

AERIAL PHOTOGRAPH OF FALKLAND GYPSUM QUARRY

(Scale 1:12000 approx.)


ACTUAL MINE
PREVIOUS MINE
SURROUNDING NATURAL FOREST
609938 SQM SLIGHTY SPOILED NATURAL FOREST
706163 SQM CLEARED FOR PREVIOUS HAUL ROADS AND MINING TESTING
72606 SQM CLEARED FOR FUTURE SPOIL DUMP
162046 SQM ACTUAL MINE AND PREVIOUS MINE
SRS 4658 -18


119° 35
119° 30
FOREST
ESSF
MS
MS
IDF
(VERY DRY HOT)
IDF
(MOIST WARM)
FALKLAND QUARRY
LAFARGE PROPERTY
Falkland
32'
31
50° 30
29'
28'
KEY
SYMBOL ZONE
ESSF ENGLEMANN SPRUCE / SUBALPINE FIR
MS MONTANE SPRUCE
IDF INTERIOR DOUGLAS FIR
Échelle 1:50 000 Scale
Mètres 1000 0 1000 2000 Metres

BIOGEOCLIMATIC ZONES

FROM LLOYD
ET AL (1989)

Following reception of the initial mandate to reclaim the former quarry, preliminary site inventories and analyses were done. Necessity to adopt a more global approach by reclaiming the whole site of the quarry including former, actual and future quarries and there impacts on surrounding land became the obvious and logical choice.

RECLAMATION PLANNING & DECISION MAKING PROCESS

INITIAL MANDATE

↓

PRELIMINARY INVENTORIES AND ANALYSIS

↓

MANDATE REVISION WITH THE CLIENT

↓

INVENTORIES
(Biophysical, visual, human factors)

↓

ANALYSIS
(Biophysical, visual, human factors + mining plan and operations)

↓

RECLAMATION CONCEPT CORRESPONDING WITH MINING OPERATIONS*

↓

RECLAMATION PLAN, REPORT & STRATEGIES*

↓

PUBLIC PRESENTATION

↓

RECLAMATION PLAN & REPORT DEPOSITING TO GOVERNMENT OFFICIALS

** with presentation to client*

SITE INVENTORIES AND ANALYSIS

1. GEOGRAPHICAL & CULTURAL CONTEXTS

Falkland is located in the recess of an elbow-shaped valley with an approximative population of 600. This Town has a resource and tourism economy base and canadian patriotism is clearly indicated by a huge flag at the summit of the former quarry. The quarry spreads over approximatively 45 hectares, between elevations 609 and 853m.

2. GEOLOGY

The Falkland deposit, originally known as the Salmon River deposit, was discovered sometime before 1889. The gypsum deposit occurs as a series of lenses extending for two kilometers along the hillside on the northeast side of Bolean Creek valley just north of Falkland. The slope of the mountain side in this area averages 30° (33%). Its major exploitation started in 1926 upon completion of the Kamloops-Kelowna branch of the CNR. Until 1956, 1.3 million tons were extracted. Two mining companies succeedly bought and exploited the site.

3. LOCAL MICROCLIMATE

Falkland is in a wet sub-zone of the interior dry belt. Most of the normal microclimatic changes related to higher elevations are offset by quarry solar exposure. Rock exposure likely increases reflection of heat and light, contributing to drier, warmer conditions that would normally occur.

4. SOILS & SURFICIAL GEOLOGY

Coarse-textured morainal and colluvial blankets of venners over rocks form parent materials of soils in the Falkland area. Surface soils are thin and consist of silty loams, sandy loams and clay loams. Surface drainage is expected to be good to very good. Existing original surface soils are a mixture of Gray Luvisols and Dystric and Eutric Brunisols. Dystric Brunisols, typically found at higher elevations, are more acidic and moist making them better suited for reforestation.

Bedrock overburden, beneath the surface soil, is composed of shale, gypsum-based roak and some argilites. These materials make up most of the volume of the quarry waste dumps. Long-term physical weathering of these materials will most probably produce fine particles suitable for plant growth and soil developement. Chemical weathering of these materials is not expected to create harmful by-products for plant growth.

5. DRAINAGE

Because of the site's climatic conditions, southern exposure and geology, there is no stream on the site. Visible drainage lines on topographic maps, but invisible on the site, do not collect enough water to sustain humid environement plants. Lack of water will be counteracted by establishing a drainage line at the base of the new spoil dump.

6. VEGETATION

The area has a canopy largely composed of mature Douglas Firs. Crown closure is of 50% to 70% depending on slope gradients. Natural forest of the site matches the surrounding forests. Forest is much thinner closer to exploitation areas and non-existent in cleared or deforested surfaces. These type of surfaces act as a form of buffer zone. They are in the process of self-naturalization and it is recommended that this reclamation plan does not intervene in these areas.

Selection for tree, evergreen and deciduous shrub plantings was done according to the B.C. Ministry of Environment inventory, the characterestics of an IDF zone, the particular conditions of the site along with regards to future public amenities. Here is a summary of the vegetation species to be used through reclamation:

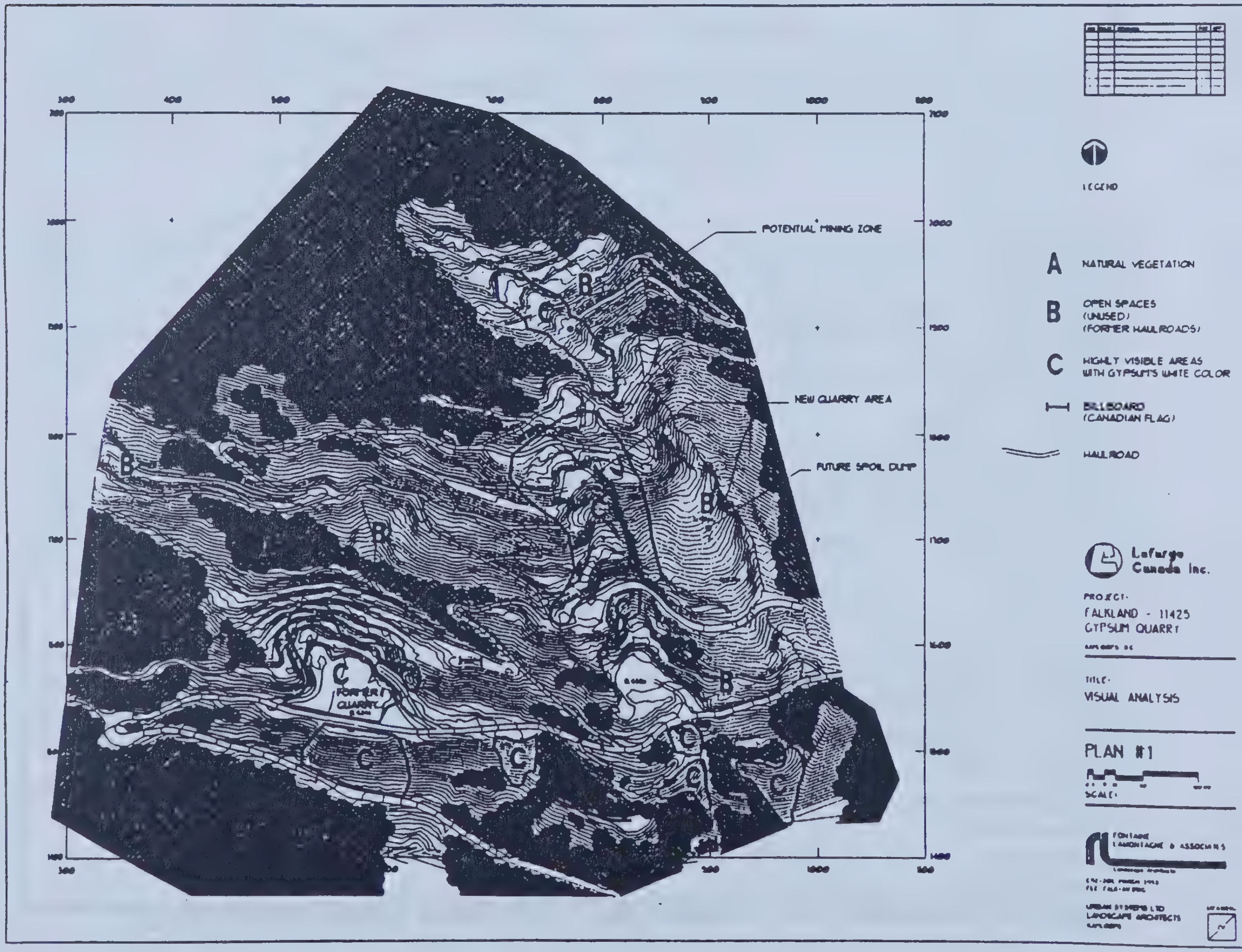
botanical names	*english names*	
TREES		
Pseudotuga menziesii	Douglas Fir	n,*
Pinus contorta	Lodgepole Pine	n,*
Pinus Ponderosa	Ponderosa Pine	nn,*
EVERGREEN SHRUBS		
Juniperus Scopulorum	Rocky Mountain Juniper	nn,*
TALL SHRUBS		
Acer glabrum	Rocky Mountain Maple	n
Alnus Tenuifolia	Mountain Alder	nn
Amelanchier Alnifolia	Common Sakatoon	n,*
Rhus Typhina	Staghorn Sumac	nn,*
Rhus glabra	Smooth Sumac	nn,*
Shepherdia Canadensis	Soopalallie	nn
LOW SHRUBS		
Spirea betufolia	Birch-leaved Spirea	n,*
Paxistima myrsinites	Oregon Boxwood	n,*
Mahonia aquifolium	Tall Oregon-grape	n,*
Symphoricarpos albus	Snowberry	nn,*
Rosa gymnocarpa	Dwarf Rose	nn,*
Ribes cereum	Squaw Currant	nn
GRASSES		
Calamagrostis rubescens	Pine Grass	n
Aster conspicuus	Showy Aster	n
Antennaria racemosa	Racemose Pussy Toes	n
Achillea millefolium	Yarrow	nn
Additional plants for diversification in touristic areas:		
Shepherdia argentea		
Rosa acicularis		
Rosa rugosa		
Juniperus Sabina		

*(n=indigenous, nn=non-indigenous, *=commonly found in B.C. nurseries specializing in native plants)*

7. VISUAL ANALYSIS

The Falkland Gypsum quarry is a highly visible feature in the otherwise lush green surrounding landscape. Numerous reasons contribute to this visibility:

1. the Town of Falkland sits in the elbow joint of the mountains, making it a pivotal axis which visually emphasizes on the quarry;
2. travellers heading to Falkland on Highway 97 are bound to have the quarry as a focal point;
3. steep slopes and large deforested areas of haul roads hairpin bends increase visibility;
4. gypsum's unique glaring white color makes its exploitation visible and its presence in overburden waste used for road foundations create extremely visible areas on the mountain's hillside;
5. a huge billboard with the Canadian flag has been set up within those very visible areas, on the summit of the former quarry at level 666. It is a regional symbol of reference and pride.


POTENTIAL MINING ZONE
NEW QUARRY AREA
FUTURE SPOIL DUMP
FORMER QUARRY
A
B
C
LEGEND
A NATURAL VEGETATION
B OPEN SPACES (UNUSED) (FORMER HAUL ROADS)
C HIGHLY VISIBLE AREAS WITH GYPSUM'S WHITE COLOR
BILLBOARD (CANADIAN FLAG)
HAUL ROAD
Lafarge Canada Inc.
PROJECT:
FALKLAND - 11425
GYPSUM QUARRY
TITLE:
VISUAL ANALYSIS
PLAN #1
SCALE:
FONTAINE LAMONTAGNE & ASSOCIATES
URBAN SYSTEMS LTD
LANDSCAPE ARCHITECTS

8. POTENTIALS & CONSTRAINTS

Located in a lush green mountain and valley landscape, the Falkland Gypsum Quarry is composed of unique wildlife, vegetation and visual qualities. These elements contribute to make tourism a local economy key factor, along with mineral resources. Therefore, it is of outmost importance that reclamation designing take into consideration human factors as well as environmental factors. This reclamation plan puts emphasis on integrating these two issues into the reclamation plan.

Steepness of the topography, quarry and quarrying activities, views of the valley, of the Town of Falkland and of the surrounding mountains are all factors of great interest.

The view of Falkland and the valley at the Canadian flag, the future first belvedere;

RECLAMATION PLANNING PROCESS

1. RECLAMATION GOALS

The following goals were established to develop the reclamation strategies and designs.

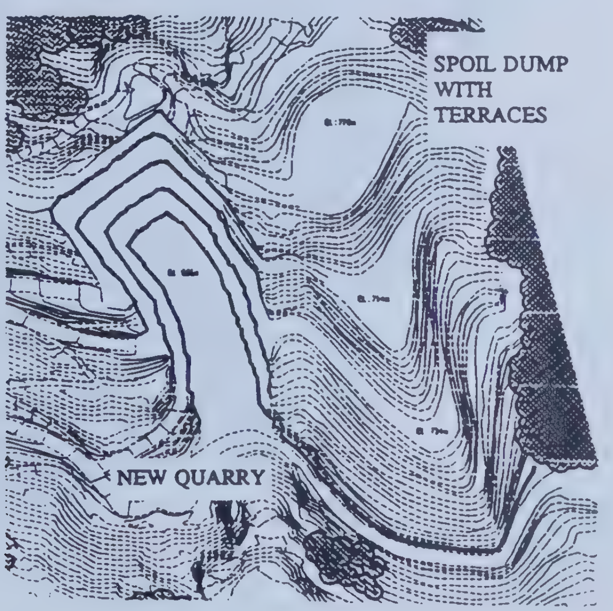
1. Comply with section 10 of the B.C. Reclamation Code.
2. Stabilize and revegetate existing open spaces and future disposal area.
3. Minimize the visual impacts of the existing and future quarries and of the overburden disposal areas.
4. Renaturalize the former quarry site and the clear-cut areas of existing hauling roads.
5. Create and manage a landscape allowing for recreational development in certain areas.

2. MINING SCHEDULE

An important part of the reclamation planning process included modifying the mining plan in order to address the overburden placement design in the new spoil dumps. Working with the client, we recommended alternatives to their extraction schedule and handling of waste material or overburden.

The Falkland Gypsum Quarry mining plan will use a basic multiple bench/open quarrying strategy. Five phases of soil deposition will form terraces across the dump to provide stability, reduce erosion and facilitate reclamation. This method creates lesser visual impact than the method used in the former quarry. The future quarry's new orientation combined with the perpendicular excavation and use of spoil dump terraces will greatly abate visual impacts as opposed to the former method which spread throughout large visually sensitive areas.

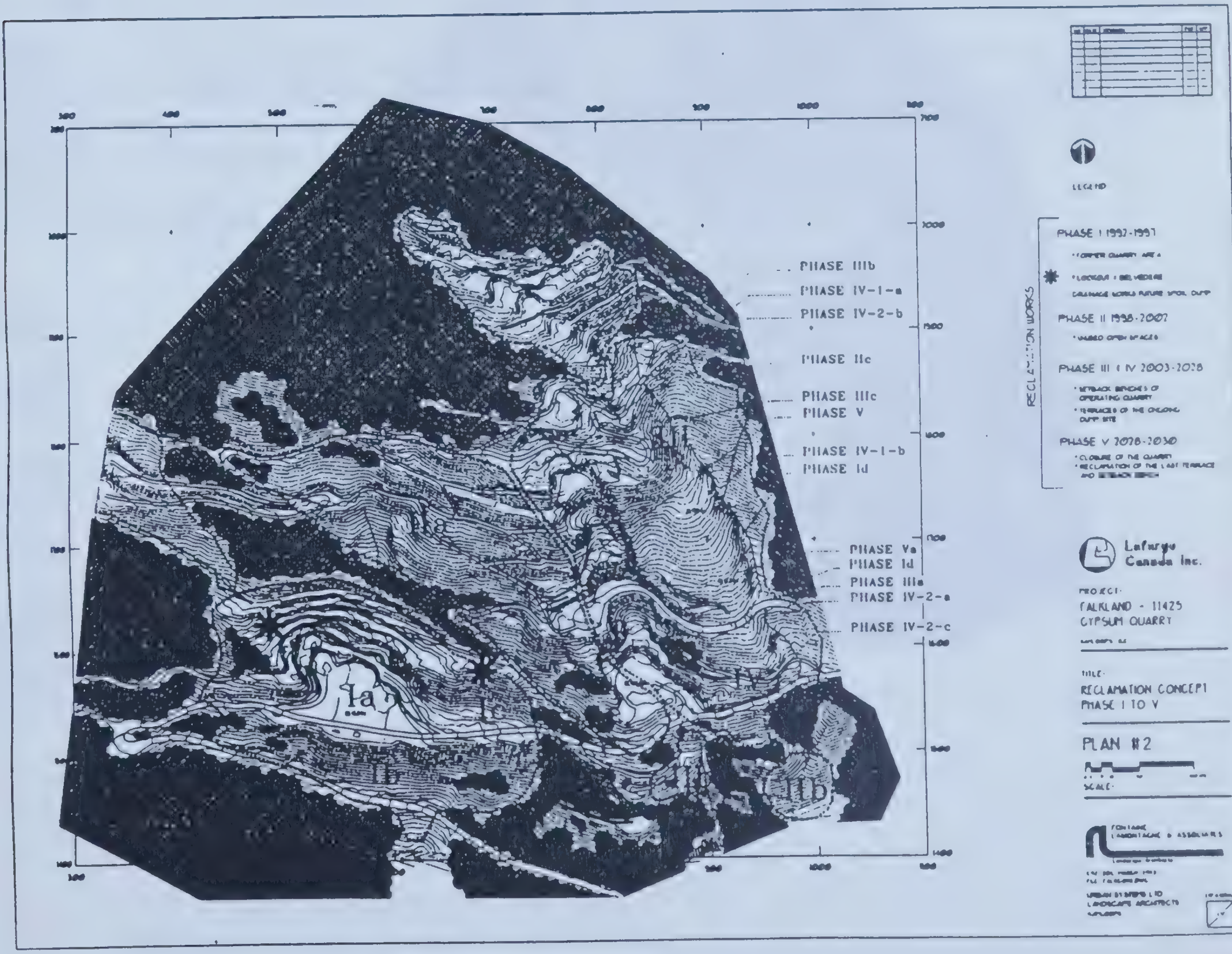
Thourough management of overdurden waste material produced by the future quarrying is a key factor of this Reclamation Plan. Overburden quantity will be significant and surrounding dump areas are relatively small and have steep slopes. Following figure shows the unreclaimed final layout of the future quarry and its spoil dump.

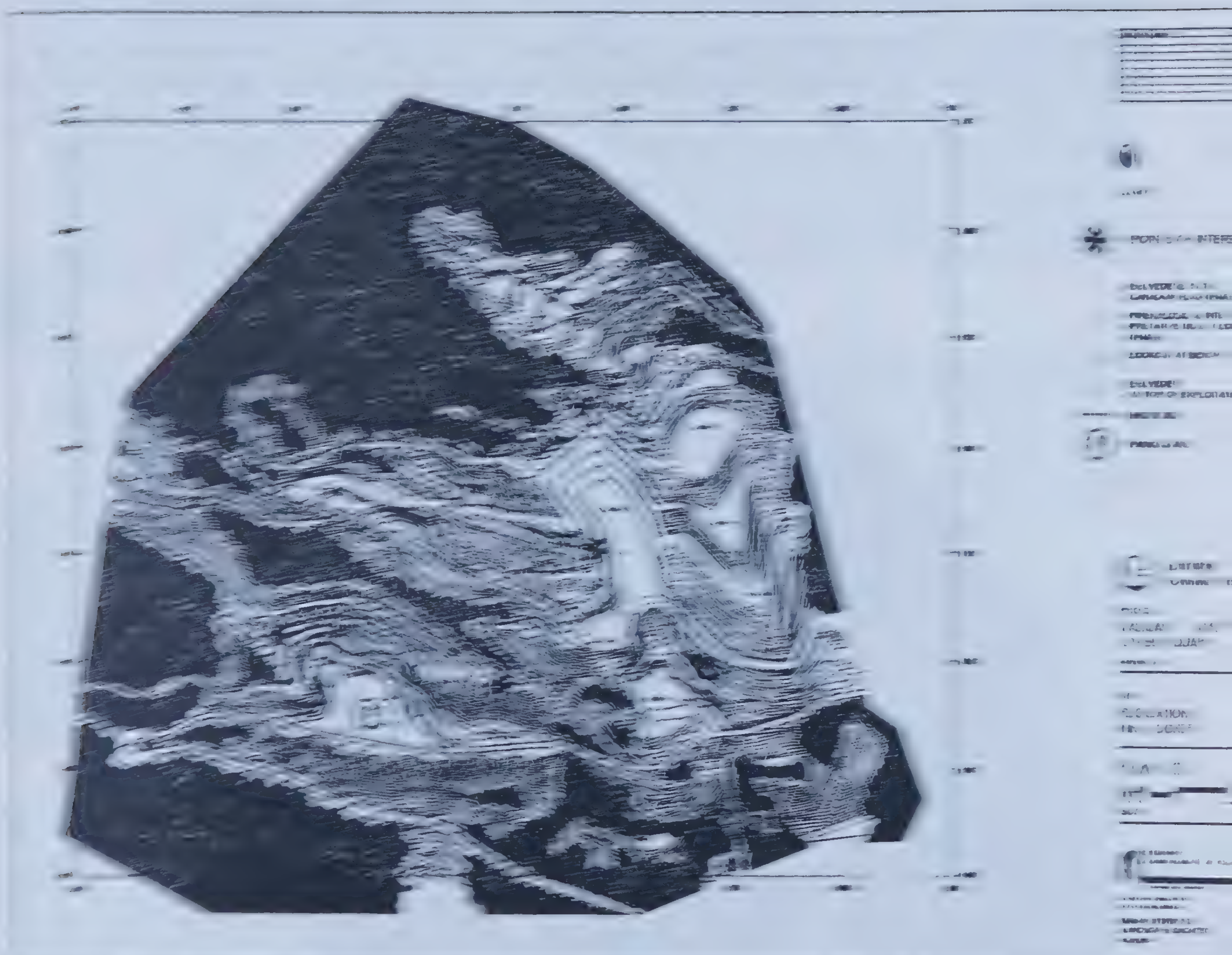


3. RECLAMATION CONCEPT

The reclamation concept is evolutionary and puts forward interchangeable reclamation interventions. It is to be applied according to exploitation development, granular material and/or plants availability and budget yearly distribution. Divided into five reclamation work phases, the concept corresponds with mining plan operations.

Phases I and II pertain to the reclamation of the former quarry, the present unused open spaces and the new haul roads. To highlight community spirit and develop tourism, recreational activity is developed around the Canadian Flag Landmark and revolve around a geological theme. **Phases III and IV** pertaining to future mining plan works include reclamation of dump site and setback benches of the quarry. Final **Phase V**, to occur at the end of mining operations, includes completion of reclamation work and a new layout for recreational activities enhancing recreational and touristic activities of Phase I.


PHASE IIIb
PHASE IV-1-a
PHASE IV-2-b
PHASE IIc
PHASE IIIc
PHASE V
PHASE IV-1-b
PHASE Id
PHASE Va
PHASE Id
PHASE IIIa
PHASE IV-2-a
PHASE IV-2-c
Ia
Ib
IIb
LEGEND
RECLAMATION WORKS
PHASE I 1992-1997
PHASE II 1998-2002
PHASE III & IV 2003-2028
PHASE V 2028-2030
Lafarge Canada Inc.
PROJECT:
FALKLAND - 11425
GYPSUM QUARRY
TITLE:
RECLAMATION CONCEPT
PHASE I TO V
PLAN #2
SCALE:
LANDSCAPE ARCHITECTS



POINTS OF INTER
BELVEDERE
LOOKOUT AT BEACH
BELVEDERE

4. RECLAMATION PLAN

Reclamation of large areas deforested for hairpin bends of haul roads and mining tests is of an outmost importance and is to be performed within Phases 1 and 2. Steep gradients of areas to be planted and renaturalized, command cautious planting operations. Planting strategies were developed to deal with this aspect.

The former quarry will be reclaimed during Phases 1 and 2. The actual quarry and its future spoil dump are the object of this reclamation plan and will be reclaimed over the next 30 years.

In realizing this reclamation plan, the Falkland Gypsum Quarry will first of all comply with the British Columbia Reclamation Code. Renaturalization and revegetation of open spaces (previous quarries and haul roads), future quarry and its spoil dump will abate visual impacts and raise the ecological value of the site. These measures are also planned, along with other landscaping improvements, to offer recreational activities.

Site revegetation, which follows a parallel thirty years schedule, includes a number of strategies ranging from straight and basic renaturalization to highly orchestrated ornemental planting. All these strategies are necessary to reduce the visual impact of the quarry and insure the safe integration of our proposed recreational activites.

The following table shows how mining operations and site reclamation relate in time.

MINING OPERATIONS & SITE RECLAMATION PARALLEL SCHEDULES

MINING OPERATIONS	SITE RECLAMATION
BENCH 1: 1993-1995 - Excavation of Bench #1 (future quarry) - Filling of terrace #1 in spoil dump	*PHASE I: 1993-1997* Ia- Reclamation work at the former quarry Ib- Reclamation of slope between haul roads in front of former quarry Ic- Recreational Activities site work -Plantings in front of Canadian flag -Construction of parking area, staircases, geological interpretative trail, pavilion and belvedere near flag with service road Id- Preliminary site work of drainage at the future spoil dump
BENCH 2: 1996-2002 - Excavation and extraction of Bench #2 - Filling of terrace #2 in spoil dump	*PHASE II: 1998-2002* IIa- Reclamation of large open spaces IIb- Reclamation work on two abandonned sites at the south-east quarry limit IIc- Reclamation work of spoil dump terrace #1
BENCH 3: 2003-2013 - Excavation and extraction of Bench #3 - Filling of terrace #3 in spoil dump	*PHASE III: 2003-2013* IIIa- Construction of 1st bioengineered retaining wall at toe of terrace #3 IIIb- Reclamation of setback bench #1 IIIc- Reclamation work of terrace #2
BENCH 4: 2014-2020 - Excavation and extraction of Bench #4 - Filling of terrace #4a in spoil dump	*PHASE IV, STEP 1: 2014-2020* a- Reclamation of setback bench #2 b- Reclamation work of terrace #3
BENCH 4: 2020-2028 - Continuation, excavation and extraction benches #4-and #5 - Filling of terrace #4b in spoil dump	*PHASE IV, STEP 2: 2020-2028* a- Construction of 2nd bioengineered retaining wall b- Reclamation of setback bench #3 c- Reclamation work of terrace #4a
BENCH 4 - END OF OPERATION: 2028-2030 -In the eventuality of quarry closure, site will be cleaned up	*PHASE V: 2028-2030* Va- Reclamation work of terrace #4b Vb- Reclamation of setback bench #4 Development of nature trails network, contruction of 2 belvederes (west side of quarry bench#3 and summit of future quarry)

RECLAMATION PLAN - PHASE I (1993-1997)

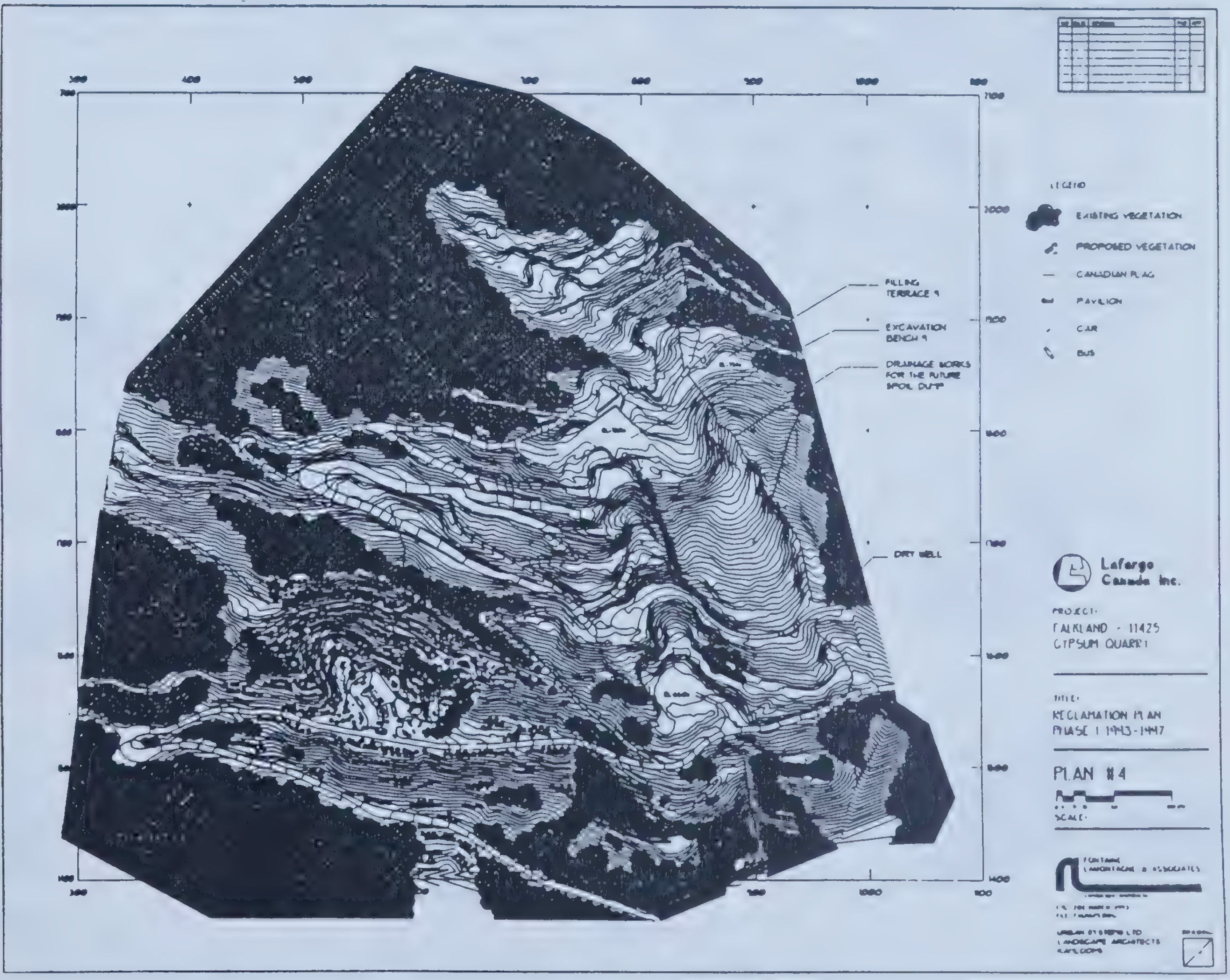
Reclamation work of the former quarry, reclamation of slope between haul roads in front of the former quarry, construction of the first belvedere at base of Canadian flag and preliminary work at the future spoil dump in order to improve drainage. Phase I roughly corresponds to the laying out period of Bench #1.

__Summary of mining operations__
Bench 1 1993-1995

The uppermost Bench #1 will produce no gypsum, but is designed to adjust the waste rock configuration and serve as the key layout of all the lower benches. The mixed gypsum and waste rock excavated between elevations 796 and 776 serve two purposes:

- *to create required catchment berm setbacks for the lower bench;*
- *to provide road access for the future waste generated from Bench #2 to the spoil dump.*

Bench 1 waste will be transported westward and the up and over top of lens to be deposited at top of dump starting at 794 elevation.

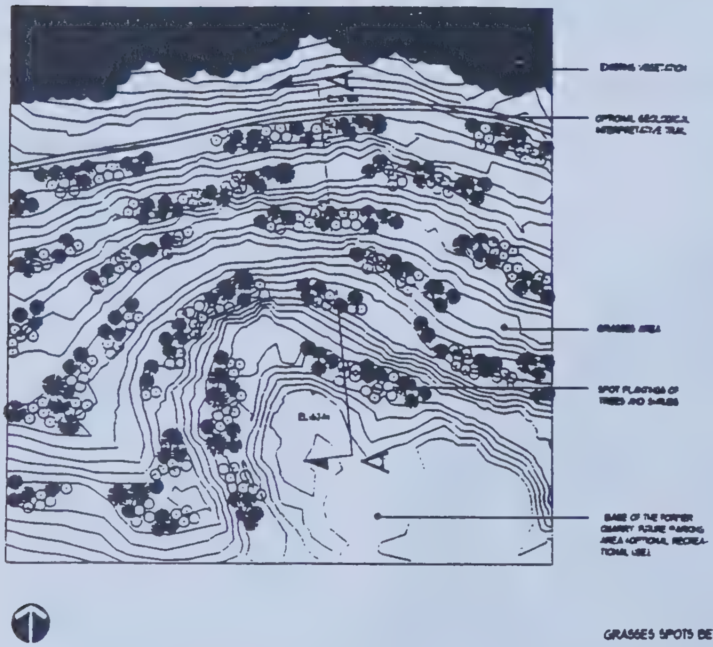

FILLING TERRACE 9
EXCAVATION BENCH 9
DRAINAGE WORKS FOR THE FUTURE SPOIL DUMP
DRY WELL
LEGEND
EXISTING VEGETATION
PROPOSED VEGETATION
CANADIAN FLAG
PAVILION
CAR
BUS
Lafarge Canada Inc.
PROJECT:
FALKLAND - 11425 GYPSUM QUARRY
TITLE:
RECLAMATION PLAN PHASE I 1993-1997
PLAN #4
SCALE:
FONTAINE LAMONTAGNE & ASSOCIATES
URBAN SYSTEMS LTD LANDSCAPE ARCHITECTS KAMLOOPS
1000
1100
900
800
700
600
500
400

Reclamation work to be done in Phase I

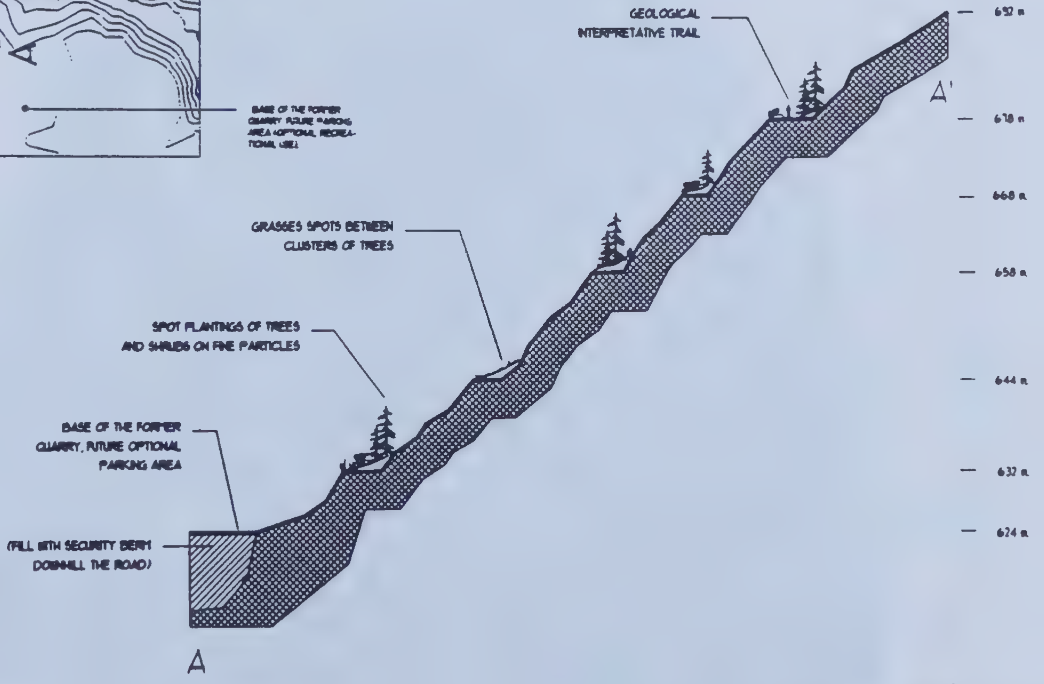
Ia- Former Quarry Reclamation : disused setback benches

The former quarry is already in the process of being revegetated. Fine particles are found on different setback benches. They are a key factor in the reclamation process and are hard to obtain on steep slopes impeding soil constitution. Width of setback benches is sufficent for small vehicular equipment managing.

Different setbak benches rehabilitation strategies were put forward. Spot planting of tree and shrub clumps with grassy areas between are directly grown on a setback bench embankment (old or new) by stripping other areas to obtain necessary growing medium in certain spots.


EXISTING VEGETATION
OPTIONAL GEOLOGICAL INTERPRETATIVE TRAIL
GRASSES AREA
SPOT PLANTINGS OF TREES AND SHRUBS
BASE OF THE FORMER QUARRY FUTURE PARKING AREA (OPTIONAL RECREATIONAL USE)
A
A'

PHASE Ia
PLAN RECLAMATION OF THE FORMER QUARRY
FIGURE 5


GEOLOGICAL INTERPRETATIVE TRAIL
A'
692 m
678 m
668 m
658 m
644 m
632 m
624 m
GRASSES SPOTS BETWEEN CLUSTERS OF TREES
SPOT PLANTINGS OF TREES AND SHRUBS ON FINE PARTICLES
BASE OF THE FORMER QUARRY, FUTURE OPTIONAL PARKING AREA
(FILL WITH SECURITY BERM DOWNHILL THE ROAD)
A

PHASE Ia
SECTION A-A'
RECLAMATION OF THE FORMER QUARRY

FIGURE 6

FONTAINE
LAMONTAGNE & A
Landscape Architects

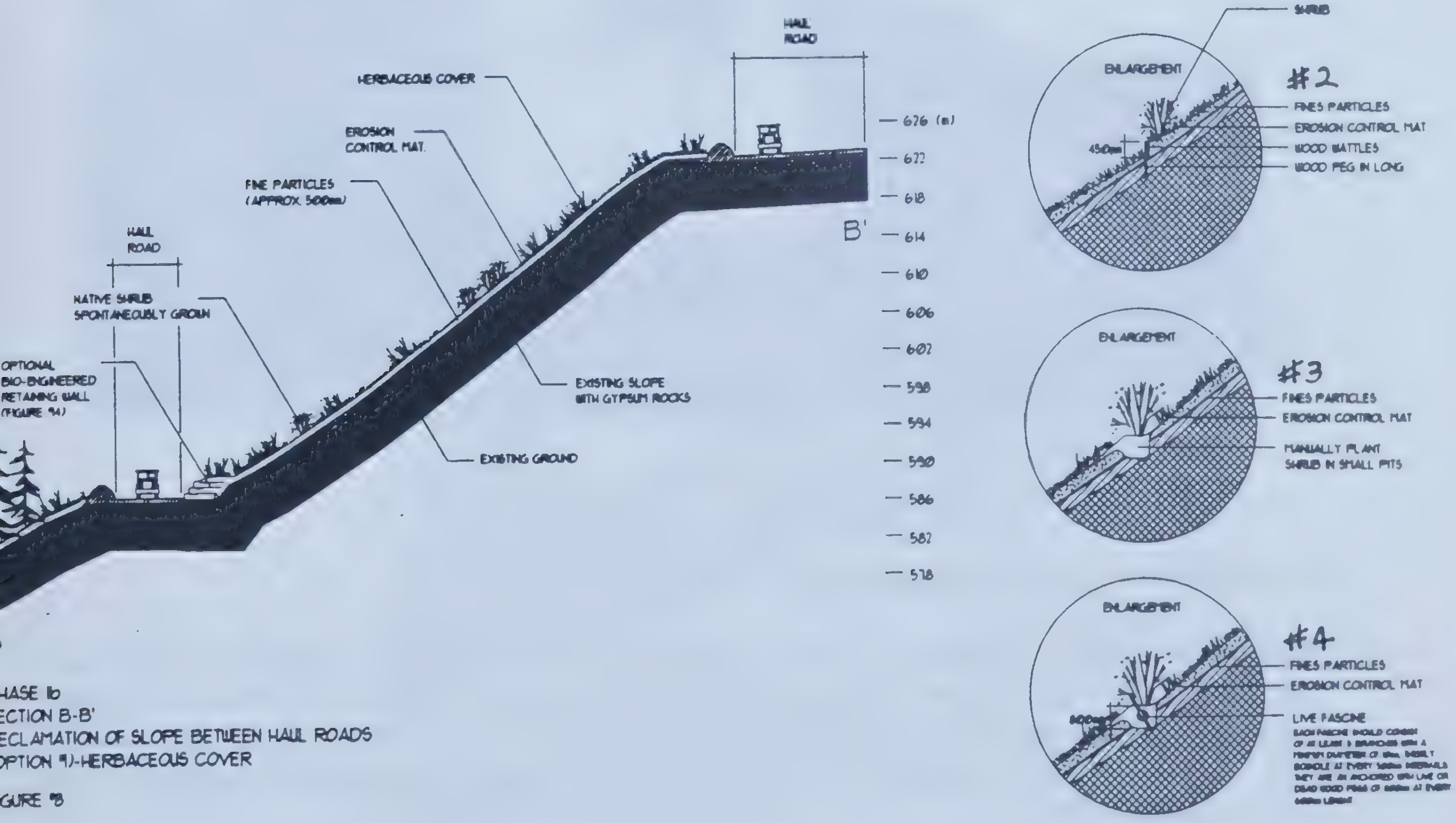
URBAN SYSTEMS LTD
LANDSCAPE ARCHITECTS
KAMLOOPS

Ib- Slopes between haul roads, in front of former quarry

Rock fill to widen haul road in front of former quarry contains a significant proportion of gypsum, is bare and spreads on large areas. This fill has a high visual impact to be abated by the establishment of a simple herbaceaous cover in which native shrubs will eventually grow spontaneously. But slope steepness commands a variety of construction methods for enabling vegetation growth.

First, actual security berm downhill of road, near quarry, will be removed to allow for fine particule unloading. Then, after eliminating large gypsum rocks, a minimum layer of 400mm of fine particles is to be spread over the rock fill and left to filter through to enable natural revegetation to take place. Erosion control mats and seeding follows (Option 1).

Structures of wattle, wicker fences to lodge thicker layers of particles will sometimes be required (Option2). These structures are to be constructed where access is possible and must follow contour lines. Erosion control mat completes this option. Another strategie increases visual complexity of alluvial cone pattern rock fill with shrub and tree spot plantings (Option 3) hand planted in deeper layers of particles areas (found or previously prepared with option 2). Last planting and renaturalization strategie consists in implementing live fascines, again to retain fine particles and enable vegetation growth (Option 4).

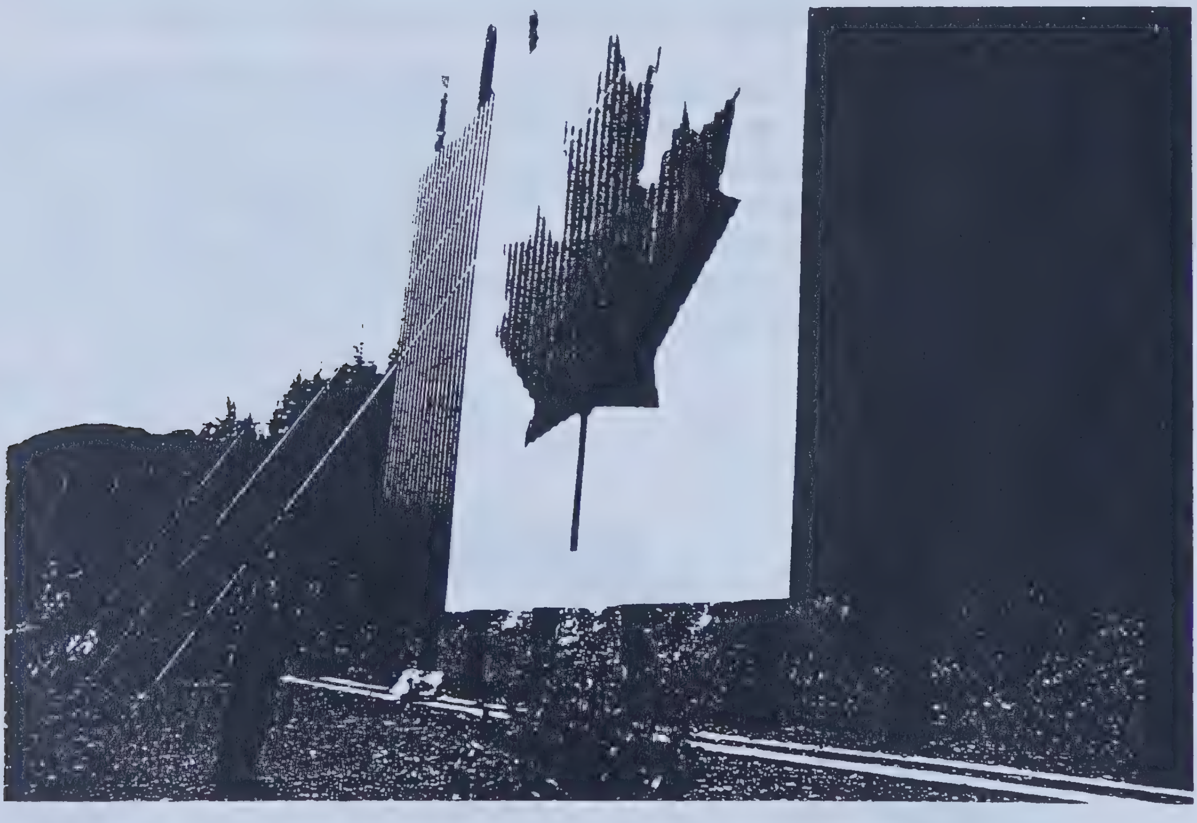

HAUL ROAD
HERBACEOUS COVER
EROSION CONTROL MAT.
FINE PARTICLES (APPROX 500mm)
HAUL ROAD
NATIVE SHRUB SPONTANEOUSLY GROWN
OPTIONAL BIO-ENGINEERED RETAINING WALL (FIGURE #4)
EXISTING SLOPE WITH GYPSUM ROCKS
EXISTING GROUND
B'
— 626 (m)
— 622
— 618
— 614
— 610
— 606
— 602
— 598
— 594
— 590
— 586
— 582
— 578
SHRUB
ENLARGEMENT
#2
FINES PARTICLES
EROSION CONTROL MAT
WOOD WATTLES
WOOD PEG IN LONG
450mm
ENLARGEMENT
#3
FINES PARTICLES
EROSION CONTROL MAT
MANUALLY PLANT SHRUB IN SMALL PITS
ENLARGEMENT
#4
FINES PARTICLES
EROSION CONTROL MAT
LIVE FASCINE
600mm

HASE Ib
ECTION B-B'
ECLAMATION OF SLOPE BETWEEN HAUL ROADS
OPTION #1)-HERBACEOUS COVER

GURE #8

Ic- Reclamation of open spaces in front of Canadian flag with shrub planting and construction of first belvedere.

This area plays a key role in the recreational proposals. First, it will be revegetated in order to abate visual impact. Then access road will be converted for public use. A lookout will be designed on the small terrace with the flag to enjoy the panoramic and spectacular views. Mineralogical/geological interpretation trail will start at the lookout and put forward geological formations, quarrying activities and explain interesting related features. Parking areas, stairways and welcoming pavilion complete the recreational layout.



The Canadian flag;

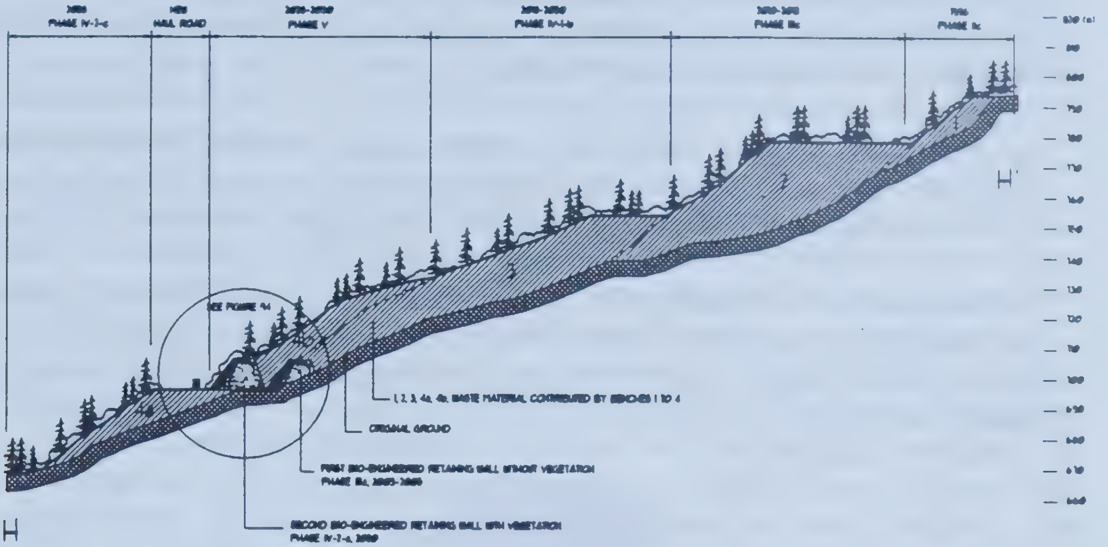
Id- Preliminary drainage work at the future spoil dump.

Preliminary work will be done at the base of the gully which will become the future spoil dump. This work will insure proper drainage on the future spoil dump and will maintain proper drainage on the present site while filling the spoil dump in the next 30 years. This riprap channel with a geotextile cover will drain water downhill and divert it into a road ditch. A dry well will soak up excess water.

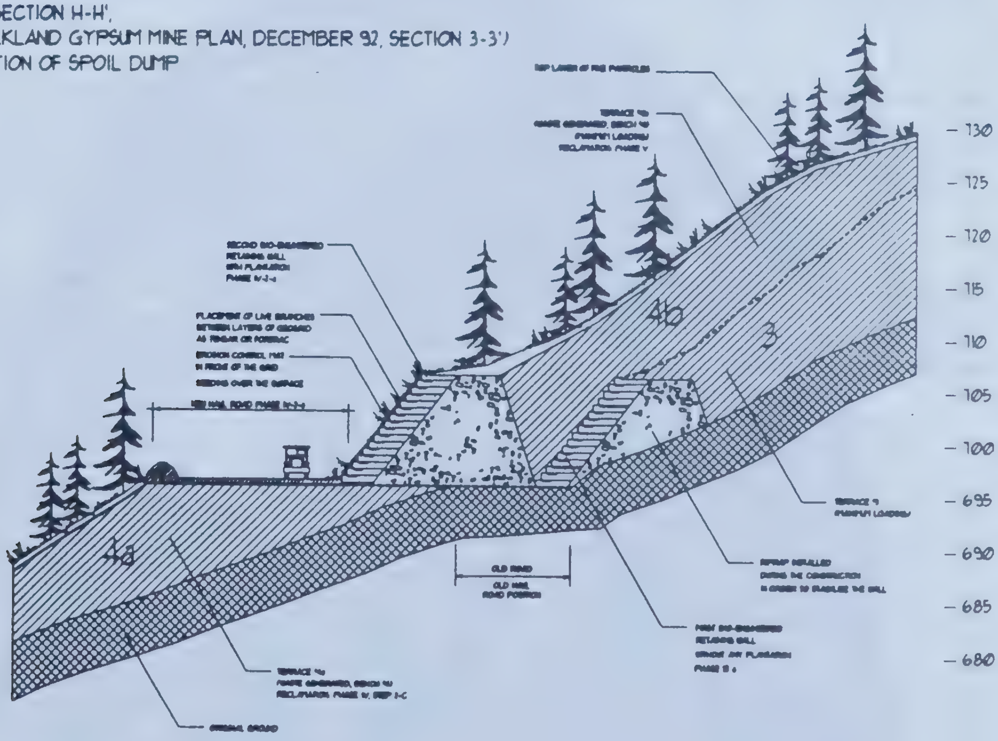
Following reclamation work examples were selected for their particular interest in this project.

RECLAMATION PLAN - PHASE III (2003-2028)

Construction of bioengineered walls will be required in order to lodge successive overburden dumping. They are built with geogrid reinforcement systems. These systems simply lay upon a compacted fondation layer of blasted stone.


HAUL ROAD
PHASE V
H
H'
2
3
4a
4b
1, 2, 3, 4a, 4b WASTE MATERIAL CONTRIBUTED BY BENCHES 1 TO 4
ORIGINAL GROUND
FIRST BIO-ENGINEERED RETAINING WALL WITHOUT VEGETATION
SECOND BIO-ENGINEERED RETAINING WALL WITH VEGETATION

TYPICAL SECTION H-H',
(FROM FALKLAND GYPSUM MINE PLAN, DECEMBER 92, SECTION 3-3')
RECLAMATION OF SPOIL DUMP


TOP LAYER OF FINE PARTICLES
SECOND BIO-ENGINEERED RETAINING WALL
PLACEMENT OF LIVE BRANCHES BETWEEN LAYERS OF GEOGRID
EROSION CONTROL MAT IN FRONT OF THE GRID
SEEDING OVER THE SURFACE
4a
4b
3
OLD ROAD
RIPRAP INSTALLED DURING THE CONSTRUCTION IN ORDER TO STABILIZE THE WALL
FIRST BIO-ENGINEERED RETAINING WALL
ORIGINAL GROUND
130
125
120
115
110
105
100
695
690
685
680

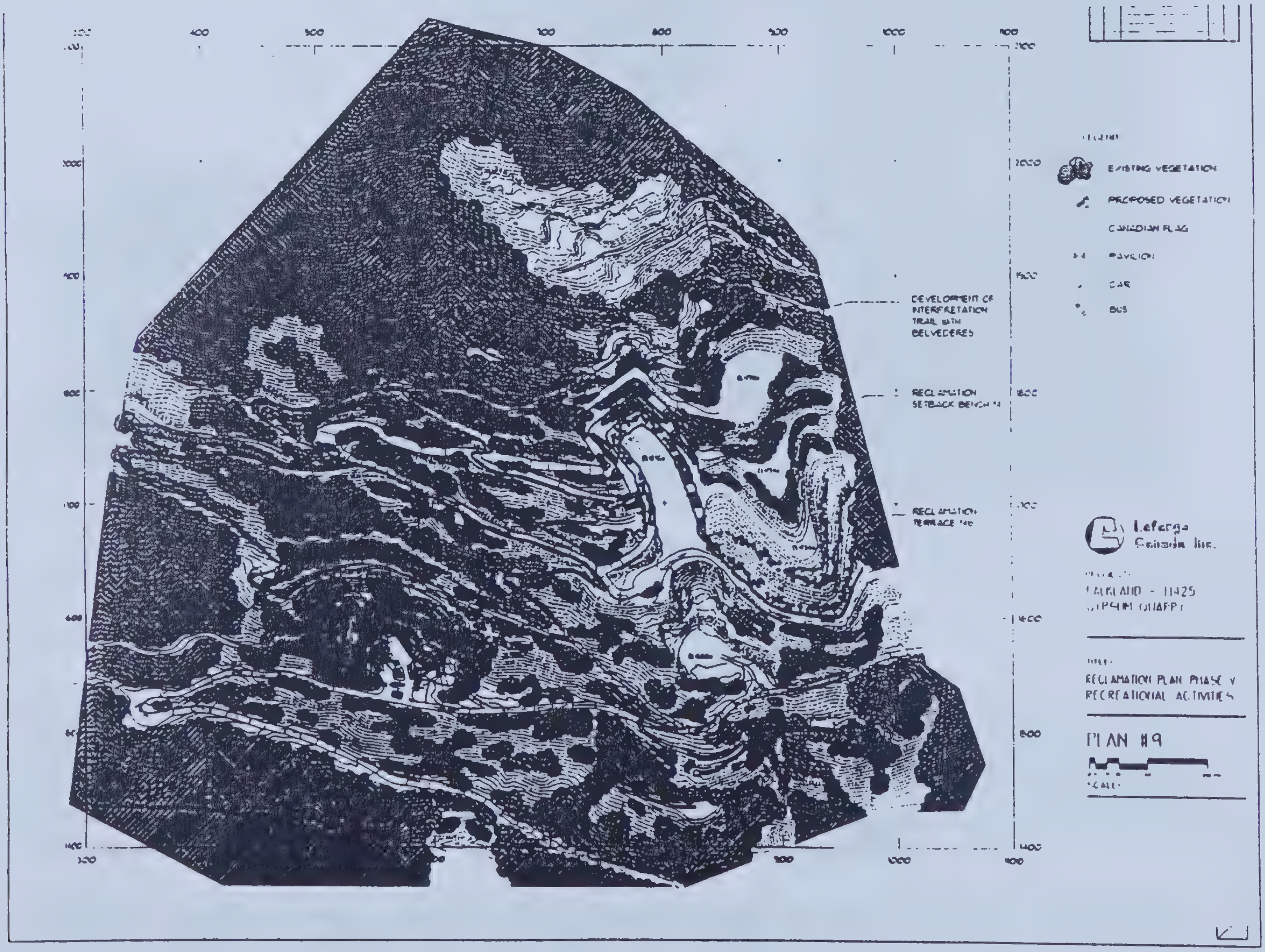
SECTION ENLARGEMENT
BIO ENGINEERED RETAINING WALL

RECLAMATION PLAN - PHASE V (2028-2030)
RECREATIONAL DEVELOPMENT COMPLETION

Reclamation of terrace #4b will occur when all waste material generated by bench #4 will have been put into place. This terrace will have to be reclaimed due to its large highly visible surface. Setback bench #4 will also be reclaimed at the end of mining operations. Recreational Phase V Plan will be performed once extraction operations are nearly completed or ended. It will pursue recreational development started in Phase I.

An observation platform located on a former loading platform, at intermediate level bench #3, will offer a sheltered place to contemplate the dramatic views of the gypsum lens exploitation and its recess plateaus. A pedestrian path links this platform to the Canadian flag lookout.

At the summit of the quarry site, another lookout is planned given the spectacular views onto the valley from this point. These views make a large part the genius of this landscape. Even treking up steep slopes is part of the genius. A network of trails links these features and recycles former haul roads.


DEVELOPMENT OF INTERPRETATION TRAIL WITH BELVEDERES
RECLAMATION SETBACK BENCH #4
RECLAMATION TERRACE #4B
EXISTING VEGETATION
PROPOSED VEGETATION
CANADIAN FLAG
PAVILION
CAR
BUS
Lafarge Canada Inc.
FALKLAND - 11425 GYPSUM QUARRY
RECLAMATION PLAN PHASE V RECREATIONAL ACTIVITIES
PLAN #9
SCALE

CONCLUSION

The former quarry creates an unsightly gash in the otherwise lush green mountain and valley landscape. This is exacerbated by its southern exposure which sharpens the already bright white color of gypsum. Amazingly, the town had chosen to capitalize on this "eyesore". By installing a giant Canadian flag, they had already started the reclamation process and invested it with meaning. Our firm understood the significance of this gesture and was compelled to respond by developing a reclamation plan that included the actual and former quarry area and enhanced it for the benefit of the community.

The Reclamation Plan surpassed the mandate of both the Reclamation Code and the client on a number of levels. By broadening our focus beyond the site of the proposed quarry, we were able to introduce a significant recreational component. The plan itself is meant to be carried out over a thirty year period, yet our proposal does not wait for quarry closure to transform the site into a public amenity. At the onset of mining operations, a belvedere and an information pavilion along with geological interpretation trail will be the first interventions. In a later phase of work, a trail and look-out network will be built to allow visitors to view the quarrying operations. At the end of mining operations, a final belvedere will be constructed offering an exceptional view onto the surrounding valleys. As a result of the reclamation process, the site's ecological value will raise. Wildlife such as deers and other mammals and bird species, will be sustained by providing better nourishment.

Our firm was entirely responsible for the Reclamation Plan. With our sub-consultants in the region, we conducted the necessary inventories. We then proceeded to redifine the scope of intervention. In addition, our firm produced visual simulations as designing tools which became part of the presentation to the Town of Falkland.

The Falkland Gypsum Quarry owner is an acknowledged leader in environmentally sound mining and quarrying strategies. Commitment towards clients, employees, communities and shareholders have built our client's reputation. Goodwill underlays these commitments, and it extends to efficient cooperation while carrying out reclamation planning and site work.

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**Please note that this article is based upon the Falkland Gypsum Quarry Kamloops Cement Plant Reclamation Planning Report, April 1993 prepared by J-G Levaque, Fontaine Bernard & Associates, Urban Syatems Ltd. The following Bibliography pertains to the aforementionned Report.*

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DECOMMISSIONING STANDARDS WORKSHOP

1. Gained an understanding of an acceptable approach to achieving decommissioning/reclamation "standards" using consistent terminology.

2. The approach recognizes three levels of detail:

- Objective - Generic
- Criteria - Accepted limits
- Standard - Adapted limits

3. Objectives include:

- Reclaim to an acceptable use
- Ensure public safety
- Minimize off-site effect on the environment
- Aesthetically acceptable
- Maintenance free

4. Criteria include:

- Broad based limits (SSWQO, MMLER)
- Industry specific
- Recognize age of operation (grandfathering, retroactivity)

5. Standards include:

- Site specific adaptation of Criteria
- Based on background conditions
- Modified by local requirements
- Recognize risk assessment to modify Criteria

6. Important to write Objective into legislation.

7. Important to keep Criteria and Standards out of legislation to ensure flexibility.

8. Any Criteria or Standards need to be science based - apply common sense and research supported.

9. Public involvement is crucial at all three levels:

- Easier in Objectives
- Less in Criteria and Standards due to lack of technical expertise
- Involvement in Objective and Criteria development
- Information/education in Standard development

10. Overlapping jurisdiction between level of Government

- Need to minimize and/or harmonize

11. For new projects the planning needs to recognize and incorporate decommissioning and reclamation.

12. Reclamation activities are more cost effective when done throughout the operating life/progressive.

13. Orphan sites
    - recommend topic for future session

14. QUESTIONS

- When does decommissioning reclamation end?
- How long does monitoring go on?
- When does company's liability end? Does it?
- Does liability end for certain aspects?

PERFORMANCE MONITORING WORKSHOP

FACILITATOR: Stella Swanson, Golder Associates
RAPPORTEUR: Peter Courtney, S.E.R.M.

GOALS The purpose of this workshop was to exchange ideas and to learn about monitoring tools available.

What is performance monitoring?

Basically this means measuring in some way what impact the development has on the environment.

This monitoring is done for many reasons and to achieve several objectives including:

- to ensure compliance with all applicable regulations,
- to demonstrate due diligence,
- to validate predictions made about design performance, environmental impact assessments, and modelling results,
- to identify any new environmental concerns that were not predicted,
- to ensure that objectives are being met (eg. decommissioning),
- to feed back information to the operation so that they can react to problems should they arise,
- to measure the functioning status of the ecosystem, such as deterioration or recovery,
- to determine when closure has been reached.

How does performance monitoring relate to:

- EIA
  - can check on EIA predictions,
  - can look at incremental impact of new development in relation to existing impacts for a number of industries in an area (= cumulative impacts),
  - can demonstrate due diligence by identifying problems in the beginning and then taking action to minimize or prevent them (= proactive),
  - can identify potential contaminant groups,
  - can identify areas of the affected environment where contaminants accumulate,
  - can identify sensitive habitats.

- **Compliance**
    - there are several distinctly different categories of performance monitoring relating to compliance; there is monitoring relating to compliance with regulated limits, monitoring related to action levels, and monitoring related to ambient environment quality guidelines,
    - quality assurance and control (QA/QC) is essential for this type of monitoring,
    - compliance monitoring may reveal a problem that requires further investigation and more sophisticated techniques (eg. Toxicity Identification Evaluation),
    - compliance monitoring provides essential information on the ongoing impact of the development. This information is used by the company to assess and make decisions, and take action in regards to the development. The information is used by government and the public to check on the ongoing impact of the development.

- **Environmental Management**
    - monitoring provides essential feedback to operation's personnel, enabling them to identify problems at an early stage and to take corrective action,
    - the success of a monitoring program as it relates to environmental management depends to large extent on having major stakeholder's input and involvement (eg. CEO, public, local landowners, Indian bands, etc.)

What are some important issues related to performance monitoring?

Numerous issues were identified by the group including:

- what is it we are really looking for when we monitor the ambient environment?
- if we measure an impact, what is the cause and is it due to the development or some other factor?
- what do we compare our monitoring results to when evaluating these data?
- how do we compare data collected 20 years ago with that collected today, knowing that sampling and analytical methods and accuracy have changed?
- how do we measure with any confidence and what judgements should we make on chemical levels measured at the parts per trillion or quadrillion range?
- should we be monitoring concentrations or loadings of contaminants?

- what proportion of short term (= relative) versus long term (= cumulative) monitoring should we do?
- just how far do we go with our quality assurance programs?
- how many samples do we collect and how much money should we be spending on monitoring?
- how is the monitoring data perceived, who gets it, and how is it used?
- how long must we monitor for?
- what is the rationale for the monitoring that is done and for the limits, action levels, and guidelines to which the monitoring information is compared?
- how do we design on overall program that will include all the elements?
- how do we deal with environmental components and sampling media that are difficult to sample in a representative way (eg. soil of sediment) or that show naturally high variability (eg. fish)?
- what monitoring will be required in the future as a result of discovery of new problems and/or changes in government regulations.
- are monitoring programs inclusive and flexible enough to do the job we want them to do?
- what are the zones of impact, mixing zones, and accumulation zones?

Discussion of selected issues related to performance monitoring

The group selected five of the above listed issues to discuss in individual discussion groups. The issues and major points of discussion are outlined below.

- How much money should be spent on monitoring and how should cost-effectiveness be determined?
  - the EIS should be the basis for determining what needs to be done,
  - more or less monitoring may be done as a result of corporate policy (ie: pro-active companies may wish to do more, reactive companies less),
  - the government may require more monitoring to build its data base; should companies fund baseline work?
  - there may be additional costs related to neighbour complaints, even though compliance with regulations has been met; therefore, community consultation is important,
  - routine monitoring may uncover problems that were not foreseen that require additional investigation and expenditure; therefore, there should be contingency planning,

  - monitoring costs can be reduced through periodic reviews, rationalization, prioritization and scheduling of "big ticket" items over several years, and by making use of in-house expertise rather than consultants,
  - goal should be to focus monitoring on parameters that are the most meaningful/relevant to the ultimate goal of protecting ecological integrity.

- Quality Assurance/Quality Control(QA/QC) - How do you choose a lab in the first place, or if you aren't happy with your present lab, what do you do? The group concluded that you should take the following steps:
  - choose three labs who are accredited (e.g. CAEL, ISO or by peer group) for further investigation,
  - send each lab typical samples for analysis of selected parameters,
  - send each lab blanks, duplicates and spiked samples for analysis,
  - identify a contact person in the laboratories for future communications,
  - visit their facilities and talk to each of them about their suitability for specific work you have and their QA/QC program,
  - based on the above investigation choose two labs, one as a main, the other as a contingency backup.

- What do you look at when looking at a QA/QC program for sampling?
  - have a clear objective,
  - take appropriate number of samples,
  - choose sampling locations appropriate to your objective,
  - ensure that the sampler is trained in using the proper sampling methods,
  - use "standard" procedures,
  - do regular audits of sampling procedures,
  - establish a chain of custody for all samples from the time they are collected until they are analyzed.
  - develop a contingency plan for re-sampling or reanalyzing should anomalous results occur.

- What is the rationale for limits?
  - there is a need for limits (and guidelines) based on site specifics in addition to those based on regional/global bases,

  - look at regional limits but develop site specific limits whenever possible,
  - we need more baseline information for areas that are being developed so that we can develop site-specific limits,
  - we need to do conduct periodic reviews of monitoring data and limits to refocus monitoring efforts
  - limits will change as further technological advances are made and as further research is completed (eg. toxicology),
  - public opinion often influences reaction to monitoring data (eg. even though a limit is not exceeded the public may still lobby for action to be taken),
  - there appears to be no clear approach to air quality limits (eg. some jurisdictions use ambient limits, others use individual source or overall facility source limits).

- Due Diligence
  - it was the group's opinion that risk assessment was the best tool to assess liabilities,
  - risk assessment and due diligence are highly specialized topics that require involvement by experts in these areas,
  - there are currently methodologies available that can be used for risk assessment (see Canadian Standards Association, CCME),
  - it needs to be recognized that there are existing versus residual liabilities,
  - industry, government, and the public share residual liability even though it is not always recognized as such. Eventually a decision has to be made that an endpoint has been reached in terms of closure and decommissioning. This decision is made by regulations but there is usually an ongoing residual risk that is accepted as part of this decision.
  - there are numerous methods and mechanisms for financial assurance available.

- Ecological Integrity

  Ecological Integrity is a worthwhile approach to measuring performance (we focussed on reclamation - and what is walk away situation particularly those with hazardous sites). Raised consultation, no answers, but
  - difficult to define,
  - will vary from land use to land use,
  - will vary from mine to mine,
  - time is a critical element which should be reflected in definition,

- in reclamation bonding.

- **Biodiversity** - should be defined in practical terms. Difficulties in using this concept were noted.

- **Aspect of time** - to what degree is this linked with reclamation bonding.

- "State of dynamic equilibrium" is more realistic than striving for stability. Taking account of how natural processes work.

- Recognizes that erosion is part of natural landscape.

- Human activity should be accepted as part of ecological integrity. Our ability to manage environmental liabilities may be one measure of ecological integrity. (Question: Should mines be held accountable to a different standard).

- Time frame is a critical part of ecological integrity. Over several generations or more society may have to deal with long term liabilities.

- We need more information on functioning of natural ecosystems. Selecting key indicators is perhaps best way of defining ecological integrity
  - e.g. biomass, growth, reproductive success,
  - what are early warning signals for loss of integrity? (need more research)

Reclaim Signoff

Definitive acceptance limits may not be feasible; so we may have to rely on models.

- Agreement that an approach should not be limited by an engineering focus, but draw on life scenarios.
- if ecological integrity is worthwhile it should give us ability to define where we will be at a certain point in time. Mining needs a practical endpoint or signoff for mining companies and society to proceed/move on.
- while possibility of trust fund was raised to deal with perpetual care such as tailing ponds, funds are best retained by companies with responsibility to pay down liabilities on an ongoing basis.

Environmental Effects Monitoring and the Mining Industry

Stella Swanson, Ph.D.

Golder Associates

What is EEM?

- A requirement under the federal Fisheries Act which calls for a sequential series of monitoring and interpretation cycles with the goal of identifying the magnitude and extent of effects from industrial discharges in the receiving environment.
- Beginning in 1992, all new effluent regulations will require regulated sites to conduct EEM.
- The first industry with new effluent regulations was the Pulp and Paper industry.

What are the components of EEM?

Pre-Design
Study Design
Core Study
Site-Specific Studies

- Pre-Design and Study Reports submitted to regional Authorization Officer of Environment Canada

- Authorization Officer advised by Technical Advisory Panel

Pre-Design Study

- one time only
- scoping, information gathering, definition of study parameters
    - plume delineation
    - habitat inventory and classification
    - resource inventory
    - mill history
    - historical receiving environment data
    - effluent characterization

Study Design

- based upon Pre-Design information
- defines study area, reference area
- selects sentinel species
- specifies sample sites, sample numbers and sample timing
- identifies supporting information that will be obtained (e.g. chemical)
- outlines QA/QC program

Core Study

- every three years
  - invertebrate community assessment
  - adult fish survey
  - supporting data: water/sediment quality, body burdens
- sublethal toxicity tests (quarterly; reported yearly)

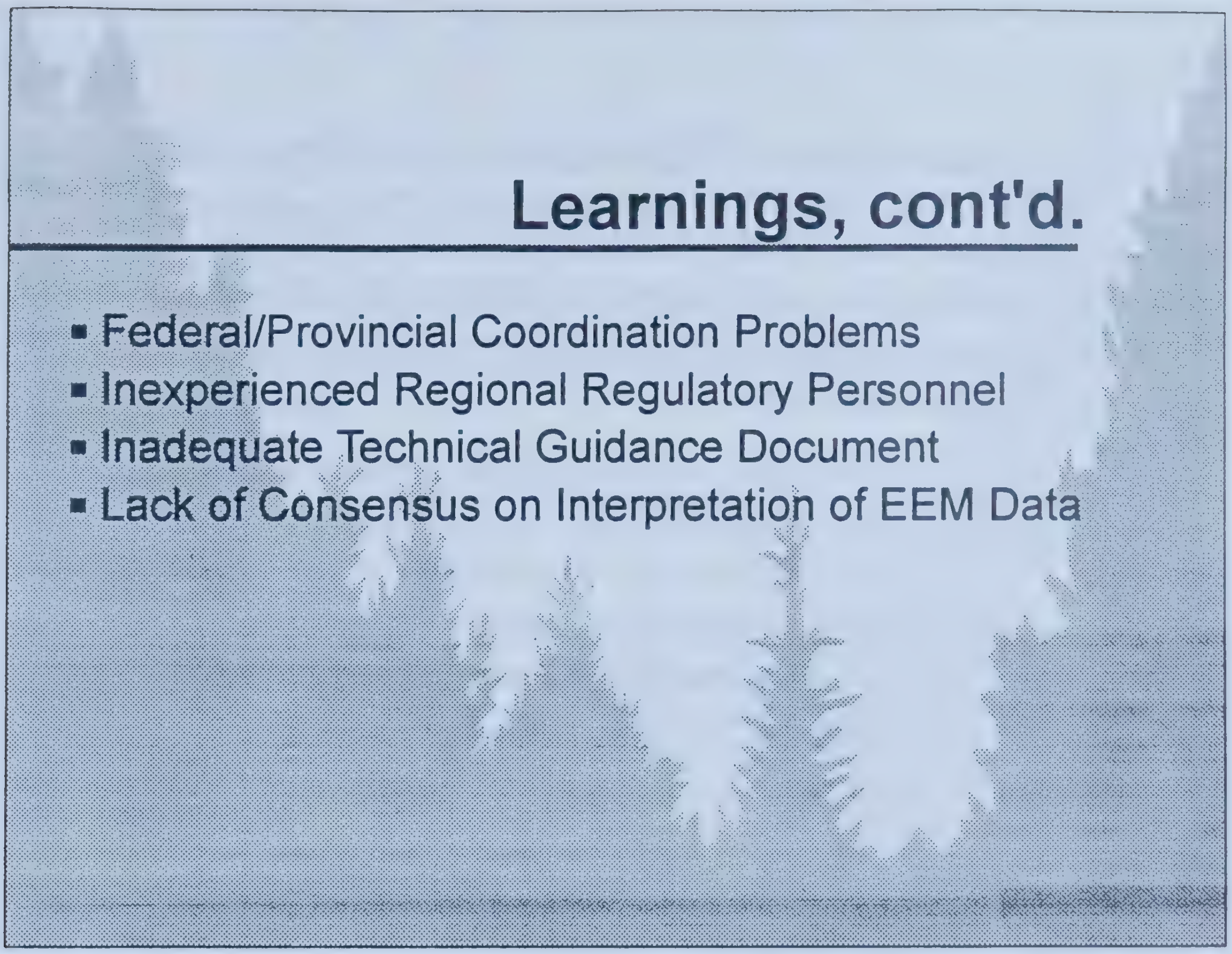
"Site-Specific" Studies

- "triggered" by a number of factors; e.g. documented concerns about fish tainting, observed effects on benthic invertebrates
- will be more common in the second and subsequent cycles

The Process Leading to EEM:

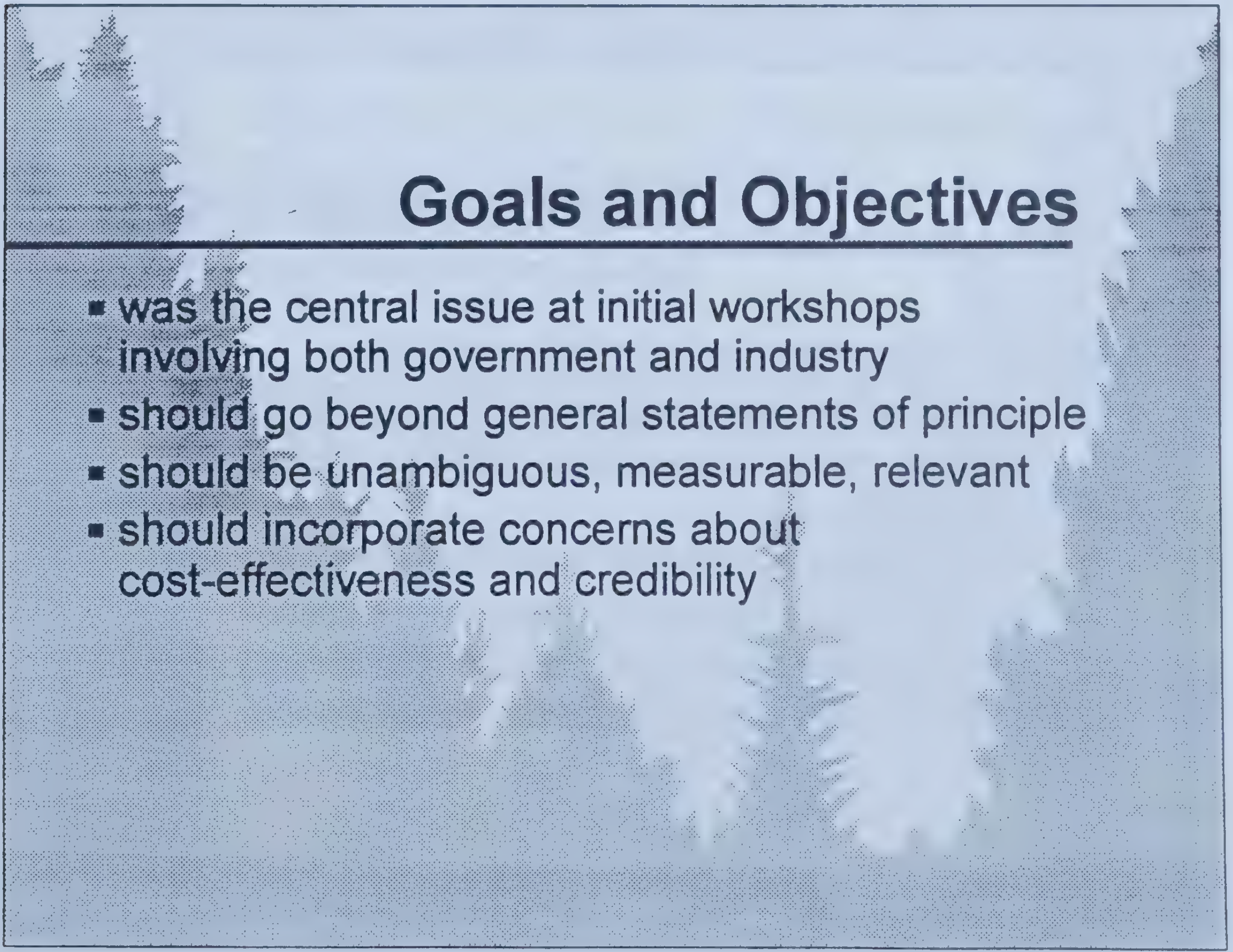
Learnings from the Pulp and Paper Experience

- Lack of well-defined goals and objectives
- National consistency versus site-specific conditions
- Difficulties with consultative process



Learnings, cont'd.

- Federal/Provincial Coordination Problems
- Inexperienced Regional Regulatory Personnel
- Inadequate Technical Guidance Document
- Lack of Consensus on Interpretation of EEM Data



Goals and Objectives

- was the central issue at initial workshops involving both government and industry
- should go beyond general statements of principle
- should be unambiguous, measurable, relevant
- should incorporate concerns about cost-effectiveness and credibility

Example of General and Specific Objectives

"to assess the adequacy of national regulations for protecting fish, fish habitat and the use of fisheries resources"

VERSUS

"95% confidence that there will be no greater difference in fish growth between a study area and a reference area than that observed to be natural variability"

Data Interpretation

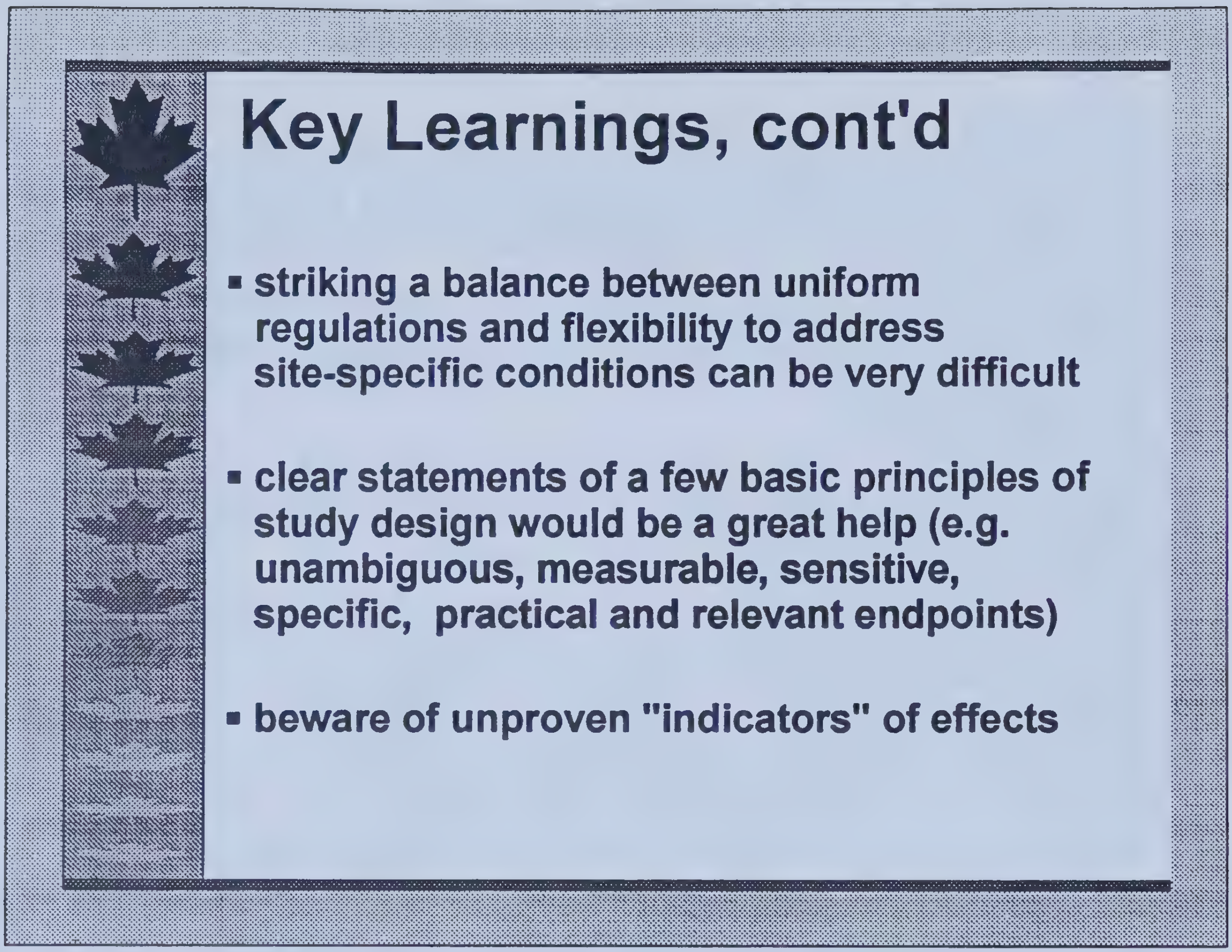
- government approach remains vague
- no statements regarding expected confidence levels (e.g. want to be 95% confident of detecting a 30% difference)
- lack of specific objectives hampers study design e.g. selection of appropriate sample sizes

Interpretation, cont'd

- adult fish survey source of much of the concern
  - simple parametric hypothesis testing may not be appropriate
  - very little known about natural variability, seasonal distribution, relationships to habitat, true extent of "exposure", resource use
  - very difficult to decide upon sentinel species, size of study area, reference areas
  - high probability of spurious cause/effect relationships

Summary of Some Key Learnings from the Pulp and Paper Experience

- **true consultation is vital**
- **input from practitioners of biological monitoring would address some of the cost/practicality issues**
- **have a clear, scientifically-credible framework for the monitoring program (e.g. criteria for problem definition, exposure assessment, effects assessment and data interpretation)**



Key Learnings, cont'd

- striking a balance between uniform regulations and flexibility to address site-specific conditions can be very difficult
- clear statements of a few basic principles of study design would be a great help (e.g. unambiguous, measurable, sensitive, specific, practical and relevant endpoints)
- beware of unproven "indicators" of effects

FINANCIAL ASSURANCES WORKSHOP

Facilitator: **Mr. Les Prosser, Robertson Stromberg**
Rapporteur: **Lorne Cooper, S.E.R.M.**

Introduction

This workshop was set up to explore what financial assurance options might be employed for various mines in Saskatchewan.

A work package was provided which included the following:

- draft Financial Assurance Regulations (Mineral Industry Environmental Protection Regulations (1995)

- a discussion of the types of financial assurances which might be available, as well as some advantages and disadvantages.(extracted from an "Evaluation of Financial Assurance Alternatives of Licensees", by John N. Douglas for Atomic Energy Control Board).

- a discussion on draft principles for an "Environmental Liability Reduction Covenant", a form of contractual agreement for reducing liability through ongoing decommissioning and reclamation during operation of an existing mine. This might be proposed as a financial assurance option to at least partially replace the building of a financial assurance fund.

- an extract from a report by a joint industry/government financial assurances taxation subcommittee, entitled "The Tax and Financial Implications of Financial Assurances for Reclamation in Saskatchewan".

- Three mining scenarios with different mine-life and liabilities.

After a brief presentation of the above material by the Facilitator, some general discussion occurred, raising the following points:

- Alberta system works to a constant reclamation scenario using a Letter of Credit. Companies used to pay on a cost per tonne basis, but this didn't work, as land wasn't certified as fast as reclamation occurred. A new system is assessed yearly with minimal administration. There are no tax implications. Some contingency is built in (about 25%). Was initially 65%, but has come down over time. More contingency is required for mountains than for prairies.

- B.C. also uses a Letter of Credit primarily, based on cost of reclamation.

- In Alberta, there is a minimal auditing process with regards to costing. There is a high level of trust in the numbers, due to experience. The general magnitude for coal financial assurance from as low as $2M to$3M, to as high as $15M. Letters of Credit work best.

- Ontario has a guideline of D&R and Financial Assurances. AECB's position is that soft assurances don't work. They have been burned by mine closures at Elliot Lake. In this instance, the company used their reputation as a guarantee. When closure came, they were broke. The public will probably be stuck with the bill for cleanup.

- "Perpetual maintenance" concept of reclamation still being used in Florida. There is apparently no ongoing discussion regarding financial assurances, but a growing realization that removal of liability is the answer.

- Concern about how to reasonably predict costs for D&R when closure is many years into the future: Possible answer - continue to project liability ahead to 5 years or less. Thus cost projections can have at least a reasonable level of confidence. If there is a low level of confidence, this will show up as an increase in the contingency.

- What protection do companies have against rules changing in the future, requiring a change in reclamation requirements.

  It was suggested that perhaps the best protection against this is to reclaim as soon as possible under existing approvals and regulatory regime.

  It perhaps should also be noted that in this era of developing partnerships, such turn of events is increasingly difficult to envisage.

Sub-Working Groups

The overall group split into three subgroups, each to evaluate one of the mine scenarios presented. The intent was to propose some financial assurance options, to fit the scenarios, and to identify questions and concerns over options and the financial assurance process. The results are attached.

Financial Assurance Workshop

Working Group Mine Scenario 1

Age of Mine: 10 years

Remaining Mine Life: 10 years

Decommissioning & Reclamation Liability (1999 $):

- *Infrastructure (bldgs; tankfarms; treatment plants; roads; pipelines; electrical; etc) - $2M*
- *Environmental (stabilize or remove tailings and wasterock /overburden/spoil; cleanup contaminated areas; recontour; revegetate; risk of failure contingency; etc.) - $2M*
- *Monitoring (during and post D&R) - $0.05 M/year*
- *Rate of Liability Accumulations as of 1999 - zero*

Time required to reclaim minesite after closure: 2 years

Post Decommissioning and Reclamation Monitoring Period: 3 years

Financial Assurance Workshop

Working Group Mine Scenario 2

Age of Mine: 10 years

Remaining Mine Life: 20 years

Decommissioning & Reclamation Liability(1999$):

- *Infrastructure (bldgs; tankfarms; treatment plants; roads; pipelines; electrical; etc) - $15M*
- *Environmental (stabilize or remove tailings and wasterock /overburden/spoil; cleanup contaminated areas; recontour; revegetate; risk of failure contingency; etc.) - $20M*
- *Monitoring (during and post D&R) - $0.20 M/year*
- *Rate of Liability Accumulations as of 1999 - $2M/year*

Time required to reclaim minesite after closure: 10 years

Post Decommissioning and Reclamation Monitoring Period: 20 years

Financial Assurance Workshop

Working Group Mine Scenario 3

Age of Mine: 30 years

Remaining Mine Life: 50 years

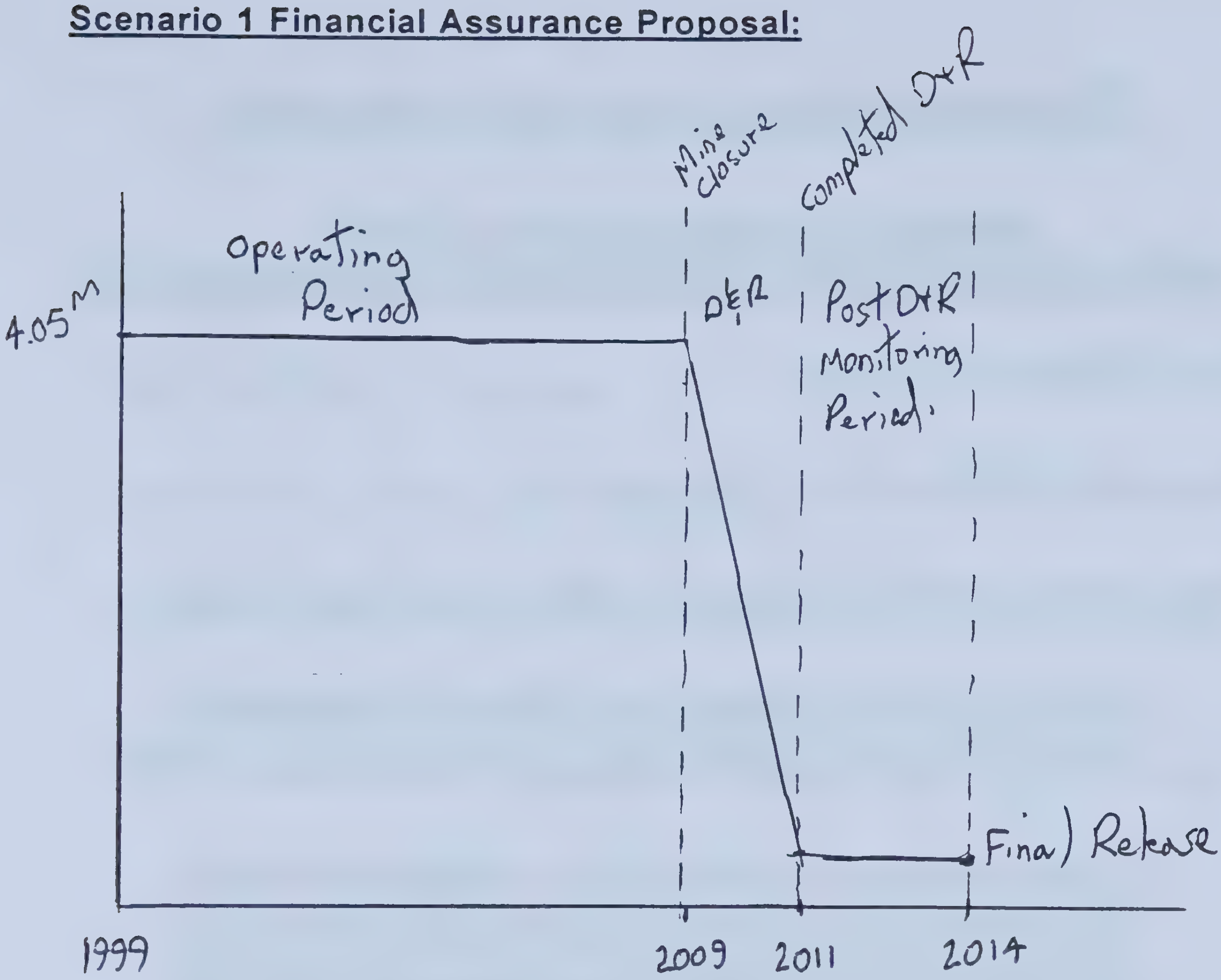
Decommissioning & Reclamation Liability (1999$):

- *Infrastructure (bldgs; tankfarms; treatment plants; roads; pipelines; electrical; etc) - $15M*
- *Environmental (stabilize or remove tailings and wasterock /overburden/spoil; cleanup contaminated areas; recontour; revegetate; risk of failure contingency; etc.) - $170M*
- *Monitoring (during and post D&R) - $0.20 M/year*
- *Rate of Liability Accumulations as of 1999 - $4M/year*

Time required to reclaim minesite after closure: 50 years

Post Decommissioning and Reclamation Monitoring Period: 20 years

Scenario 1 Financial Assurance Proposal:



Options:

1.	Letter of Credit	-	100% (yearly cost $40,000/year @ 1%)
		-	+ Contingency
2.	Trust Fund	-	10 years to accumulate
		-	approximately 300,000/year
3.	Asset Pledge		
4.	Trust/Letter of Credit		

Scenario 1 Financial Assurance Proposal: (continued)

Other Points to Consider:

- Letter of Credit a good instrument for multi-mine or diversified company. It has a reasonable cost, (1/4% to 2%/annum) and the cost is tax deductible.

- If using a Letter of Credit, must still have the full amount in cash at the end of the mine life, to actually carry out the work, as well as to continue obtaining a Letter of Credit.

- Single mine companies and junior companies may have trouble obtaining a Letter of Credit. If they have to put up a trust fund and haven't got the cash, they might not continue to obtain an approval to operate (ie: concern over crippling the juniors).

- Would a Letter of Credit have to be maintained from year 10 to final release (ie: during D&R work and post D&R monitoring?).

- **Trust Funds** raise a concern about taxation of a trust fund, if that were used. Double taxation of the interest makes a trust fund unattractive.

- For a single mine operator, however, a trust fund may be the only choice.

- Expensive, ties up capital.

- **Pledge of Assets:**
  - there is a problem of valuation, identifying salvage value, and the ongoing (annual?) valuation costs.
  - a general concern over the viability of this option.

- have difficulty with assurance for post reclamation monitoring, and how to cover this component of the assurance.

- would like to see a level playing field, although discussions revealed just how difficult maintaining a level playing field would be. Site specificity may rule in spite of desires to the contrary.

Scenario 2 Financial Assurance Proposal:

Assumptions:

a) The mine in question is a 'uranium' mine.

b) The facility is owned by a large mining corporation that has at least two mining facilities operating or under development.

c) Infrastructure liability will accumulate at a rate of $250,000 per annum for the remaining 20 year operating life, for an additional total of 5.0 M$.

Achievement of Assigned Tasks:

- Decommissioning 'Infrastructure' & 'Environmental' features = $35M + $5M = $40M at the end of remaining 20 years of life.

  A 'Letter of Credit' for a maximum of $40M will be required of the Company.

- The rate of liability accumulation of $2M/year will be accommodated by a 'Contractual Agreement' within the license that will require the Company to actually spend a minimum of $2M/year in approved decommissioning activities.

  The Company performance will be assessed during each licensing review to ensure that the Company has met its agreement.

  This action will maintain the total outstanding liability at a maximum of $40M.

- It is estimated that monitoring costs during decommissioning (10 years) and post-decommissioning (20 years) at $200,000/year will reach a total of $6M.

  The Company will establish an investment instrument (ie: term deposit, GIC) that will generate an investment income of $200,000/year for 30 years after closure or one that will generate a monitoring fund of $6M during the remaining 20 years of operating life.

- At the end of the remaining 20 years of operating life there will be an accumulated decommissioning liability of $40M. The major concern is whether a financial institution will continue to annually issue a 'Letter of Credit' for the diminishing outstanding decommissioning liability for a period of 10 non-operating years (ie: start at $40M and reduce it $4M each year for 10 years).

  The financial institution will likely do this if the large corporation has put up sufficient and acceptable assets to secure the instrument.

  In the case of a Company with other profitable operating facilities in place, this is an acceptable scenario.

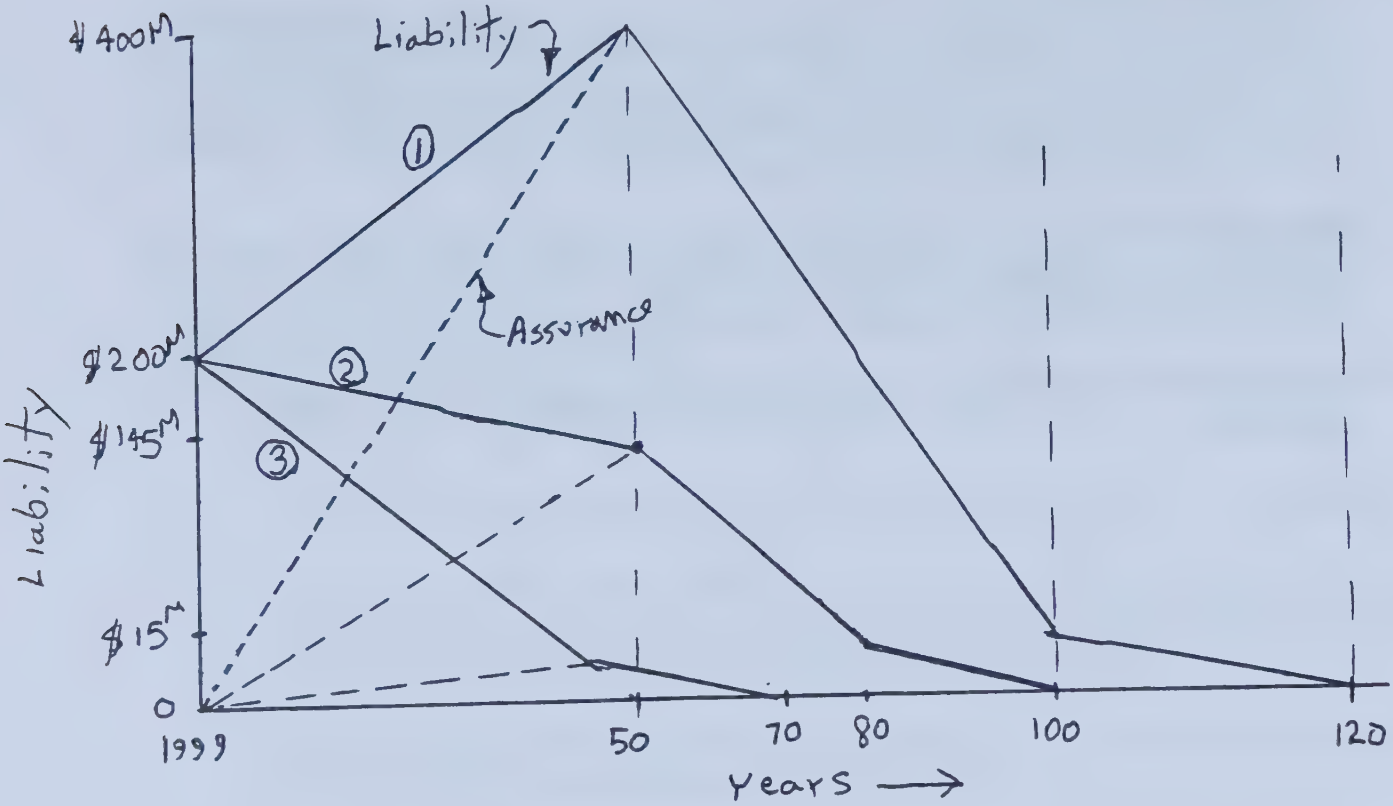
Scenario 2 Financial Assurance Proposal: (continued)

If, during annual or bi-annual reviews in the 20 year operating life a concern is identified that the likelihood of a constantly renewed 'Letter of Credit' during the 10 post-closure decommissioning years is not assured, it would be necessary for the Company to build-up a cash fund sufficient to pay for carrying out the remaining and approved decommissioning activities.

- Since this is a uranium mine that will have operated a total of 30 years the probability of any guaranteed return on salvage is very much in question. For this reason it was not taken into account in developing a financial assurance package.

  The question of salvage is an issue that will require further analysis and discussion.

Scenario 3 Financial Assurance Proposal:



1) Status Quo
2) $5M per year
3) $8M per year

	OVER FIRST 50 YEARS			
			Assurance	
Option	Ongoing Reclamation	Fund	Amount	Cost
1	$0M/Year	$8M/Year 0-$400	LOC(Hard) 200-14	1%
2	$5M/Year	$3/Year 0-$150	Soft ? 200-10	0?
3	$8/Year	0	Soft 200-4	0

Scenario 3 Financial Assurance Proposal: (continued)

Issues

Option 1
a) Risk of failure contingency (25%)
b) Tax implications on trust fund

Option 2
a) Per Option 1 but lower impact
b) Soft or hard assurance
c) Corporate tax level

Option 3
a) Per Option 2 b) and c)

Saskatchewan

Saskatchewan
Environment
and Resource
Management

Industrial Branch

October 25, 1995

To: All Mining Companies

RE: Financial Assurance Options for Mine Decommissioning and Reclamation

As discussions continue regarding options that might provide financial assurances for mine decommissioning and reclamation, one unusual but potentially attractive option appears to be development of a contract or "covenant". This would allow a company with an existing mine to carry out liability reduction work at their minesite in place of , or to supplement, a cash fund. The intent would be to satisfy the requirement for financial assurance, while permitting the company to complete decommissioning and reclamation work while the mine is still operating. The legal and practical value of such an agreement must still be determined, but discussions to date are promising.

If contractual agreements or covenants prove to be a useful option to provide financial assurance for mine decommissioning and reclamation under the "Mineral Industry Environmental Protection Regulations," a set of guiding principles will be needed. A tentative list of principles is attached.

This list is for discussion purposes only. It does not represent a position or departmental policy. It is intended to clarify the expectations of the Industrial Branch with regards to any potential contractual arrangements which might be achieved to provide a "financial assurance" mechanism. Some illustrative graphs are attached to show liability vs funding over time for three different potential scenarios.

This package is intended to provide some detail to a concept which has been discussed briefly with several mining companies. We are hoping to generate further discussion, and look forward to your questions and comments.

Lorne Cooper

Acid-free Paper

Draft Principles for An Environmental Liability Reduction Covenant
for
Mine Decommissioning and Reclamation Financial Assurance

- Agreement to be binding upon both parties
- Must include commitment to environmental liability reduction
- Must recognize that for existing sites, with large environmental liabilities, full funding or liability reduction will take several years
- Must include a detailed schedule and firm dates for achievement of goals
- Must commit to a specific value of liability reduction per annum

    - might be averaged over a period of years to account for economic cycles

- Should be an "either, or" agreement. Either reduce liability or contribute to an assurance fund, (or both)
- Will fulfill, **not** circumvent, the regulatory obligations

    -Specific work to be predetermined as an approved decommissioning and reclamation plan, in accordance with best technology for the site
    -Requires accurately measurable milestones, markers or goals
    -Will include annual reports and periodic reviews

- Should be supplemented by some form of "soft" financial assurance on an interim basis
- Qualifying liability reduction must be a NET reduction

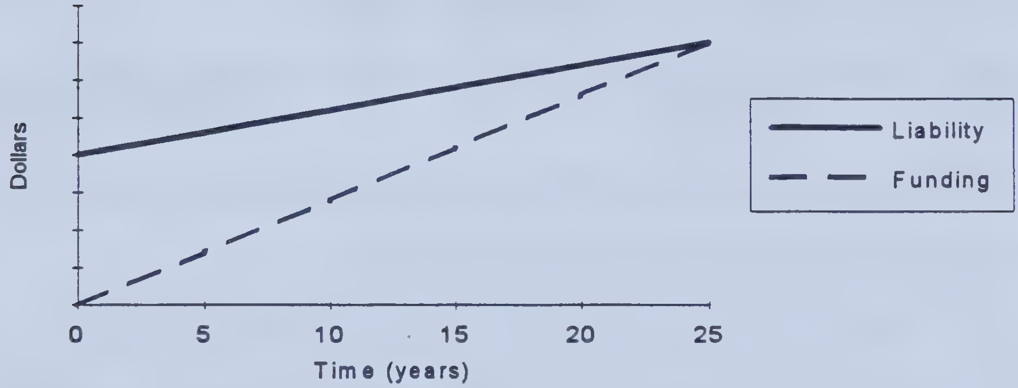
    - liability reduction measures would qualify to the extent that they exceed liability increases during the time period.

- Research into environmental liability reduction methods is **not** a substitute for actual liability reduction
- Should recognize that environmental liability reduction during operation cannot reduce liability to zero. Therefore, some supplemental funding arrangement will be necessary.
- Main Targets for Liability reduction (list not intended to be complete or limiting):

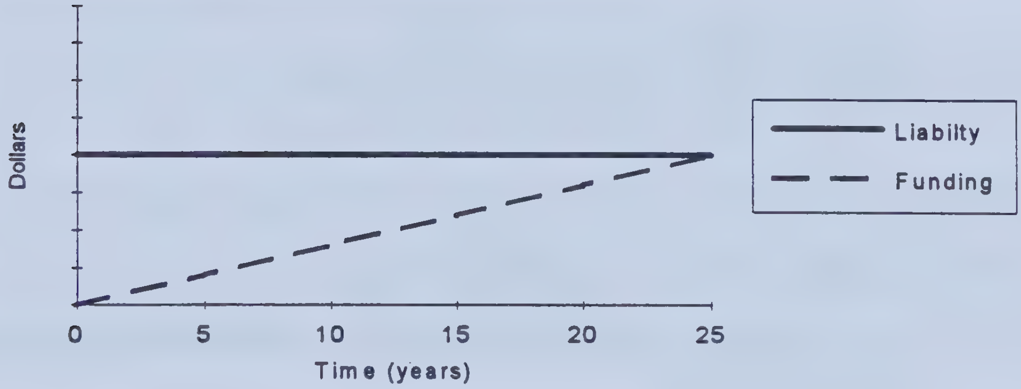
    - tailings disposal and cleanup of tailings management areas
    - surplus and abandoned buildings and infrastructure
    - hazardous materials such as asbestos
    - miscellaneous contaminated areas outside of the tailings management area, such as old spill sites or areas of past pollutant leakage or containment

Liability & Financial Assurance Funding For Existing Mines

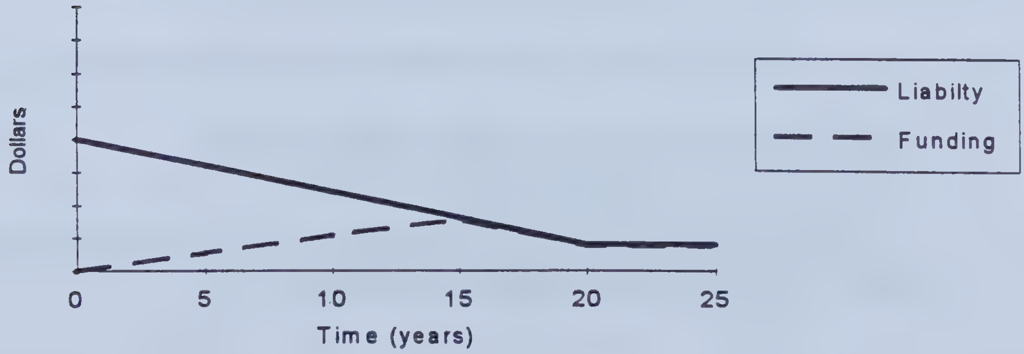
Liability Increasing - Fund Increasing



Liability Constant - Fund Increasing



Liability Reducing - Fund Increasingat Low Rate



DESIGNING FOR DECOMMISSIONING WORKSHOP

Facilitator: Ken Crane, Luscar Coal
Rapporteur: Liz Quarshie, Cogema Resources

1) Workshop Purposes:

- encourage individual participation
- identify a range of issues
- generate a list of issues
- develop groupings of issues into "themes"

2) Approach:

- introduction and obtain agreement on workshop purposes and "focusing question"
- brainstorm issues relevant to focusing question
- group issues into themes (some issues fall into multiple themes)
- divide participants into equal size groups, each representing a theme
- each theme group develops important considerations and components in "Designing for Decommissioning"
- presentations by each theme group

3) Focusing Question:

What do you believe are the most important issues that face the mining industry in "Designing for Decommissioning?"

THEME: "GEO" ENVIRONMENTAL & ENGINEERING

Issues:

1) geotechnical - long term stability
2) comparison of other industry standards and requirements
3) designing for flexibility
4) behaviour of material (characteristics)
5) modelling
6) water release standards
7) test sites to verify design
8) zero effluent
9) perpetual maintenance
10) reducing liability
11) reintegration of reclaimed land into social context
12) ability to predict and quantify impacts
13) technology for tailings disposal
14) long term performance monitoring
15) models, confidence, time frame
16) changing technologies
17) understanding risk
18) target for zero maintenance
19) long term economic/environmental sustainability
20) design to meet land use needs
21) old school of thought
22) design for a specific recurrence interval
23) design from case studies
24) understanding conditions
25) international companies
26) mechanisms for design criteria

THEME: REGULATORY

Issues:

1) acceptance of design using B.A.T.
2) Federal vs. Provincial - duplication/conflicting
3) financial assurances
4) modelling
5) water release standards
6) zero effluent
7) perpetual maintenance
8) public involvement (acceptable end land use)
9) no net loss (range beyond wildlife/fish/habitat)
10) relationship of bond to actual cost/risk
11) old vs. new (different standards - different times)
12) operations that pre-date regulations
13) reducing liability
14) ability to predict and quantify impacts
15) long term performance monitoring
16) approval of design
17) mechanisms to account for changing times, standards, economics
18) understanding risk
19) lack of government direction
20) design to meet land use needs
21) more First Nations design and jurisdiction input
22) when is it done?
23) changing government direction and how do you plan for it
24) old school of thought
25) decommissioning standards
26) design for a specific recurrence interval
27) international comparisons
28) mechanisms for design criteria - reasonable and realistic

THEME: FINANCIAL

Issues:

1) what is realistic/priorities
2) financial assurances
3) systematic updates of costs
4) zero effluent
5) convincing B.O.D. to design for decommissioning
6) relationship of bond to actual cost/risk
7) reducing liability
8) mechanisms to account for changing times, standards, economics
9) understanding risk
10) long term eco/environ sustainabilitity
11) old school of thought
12) mechanisms for design criteria - reasonable & realistic

THEME: PLAN

Issues:

1) company reporting policy - paper trail
2) designing in flexibility
3) modelling
4) convincing B.O.D. to design for decommissioning
5) what are design objectives
6) no net loss
7) old vs. new - different standards/times
8) reducing liability
9) reintegration of reclaimed land into social context
10) minimizing disturbed areas
11) models/confidence/time frame
12) design towards decommissioning
13) mechanisms to account for changing times, standards and economics
14) understanding risk
15) target for zero maintenance
16) holistic view - day 1 to end
17) time frame for decommissioning - liability
18) changing government directions & how do you plan for it
19) old school of thought
20) staged decommissioning

THEME: PUBLIC & STAKEHOLDER RELATIONS

Issues:

1) convincing B.O.D. to design for decommissioning
2) public involvement (acceptable end land use)
3) public response to results (need public confidence)
4) old vs. new - different standards/different times
5) operations that pre-date regulations
6) re-integration of reclaimed land into social context
7) models/confidence/time frame
8) approval of design
9) land ownership/public vs. private
10) understanding risk
11) design to meet land use needs
12) First Nations input - design and jurisdiction
13) old school of thought
14) public education

KEY POINTS FROM THEME GROUPS

1) "GEO" Environmental & Engineering

- have a sound understanding of site conditions and end land use objective
- define acceptable risk, based on prevailing social & economic conditions and recognizing that these are constantly changing over time
- design the decommissioning plan based on acceptable risk and at the least cost
- a "feed-back" mechanism is required to revisit the plan to account for changing conditions (physical, social & economic)

2) Regulatory

- must have a complete understanding of the major regulatory issues affecting decommissioning design:
    - the regulatory system/how was it developed
    - the review/approval system
    - standards and criteria
- even in the absence of design standards, industry has to "take the bull by the horns" and develop decommissioning plans. Absence of standards should not be viewed as a restriction - the process should be viewed as dynamic
- the regulatory system has to be interactive - "feed-back loop"
- move to self-regulation is inevitable/audits necessary
- public involvement is key to avoid impression of "fox in the chicken coop"
- Government/Industry Partnerships endorsed (eg. Potash)

3) Financial

- must determine what is realistic and establish priorities (eg. how realistic is "zero effluent" - nothing to decommission)
- decommissioning is now part of B.O.D.'s vocabulary - not so in the past, still a ways to go
- spend reclamation/decommissioning dollars while you are operating - reduce liability
- question need/amount of financial assurance if you are designing for decommissioning - don't make it a disincentive to economic activity
- objectives have to be defined in order to develop a plan which you can then cost
- difficulty in determining "costs" to future generations
- increase public awareness

4) Plan

- understanding risk is key, but complicated because standards are not clear
- in some cases technology has to be developed, therefore, you can't develop or cost the plan
- plan must be flexible to account for changes/unforeseen
- staged decommissioning is preferable - less cost and reduced liability
- discrepancies between Provincial/Federal regulations need to be reconciled - regulations can't be unachievable
- develop generic guidelines, then be site specific
- must determine end land use

5) Stakeholder & Public Relations

- Primary - any member of public who will have an interest and who may be affected (eg. First Nations, Prov/Fed government, project owners/shareholders)
- Secondary - special interest groups (no direct ties to project)
- involve primary stakeholders from the outset and keep involved throughout project life
- set objectives common to all primary stakeholders
- establish end land use/develop conceptual model
- allow feed-back leading to final concepts near time of decommissioning
- involve public in methods/technology to be used
- all of above to be done in atmosphere of "trust"; use education, consultation vs. information; be proactive not reactive